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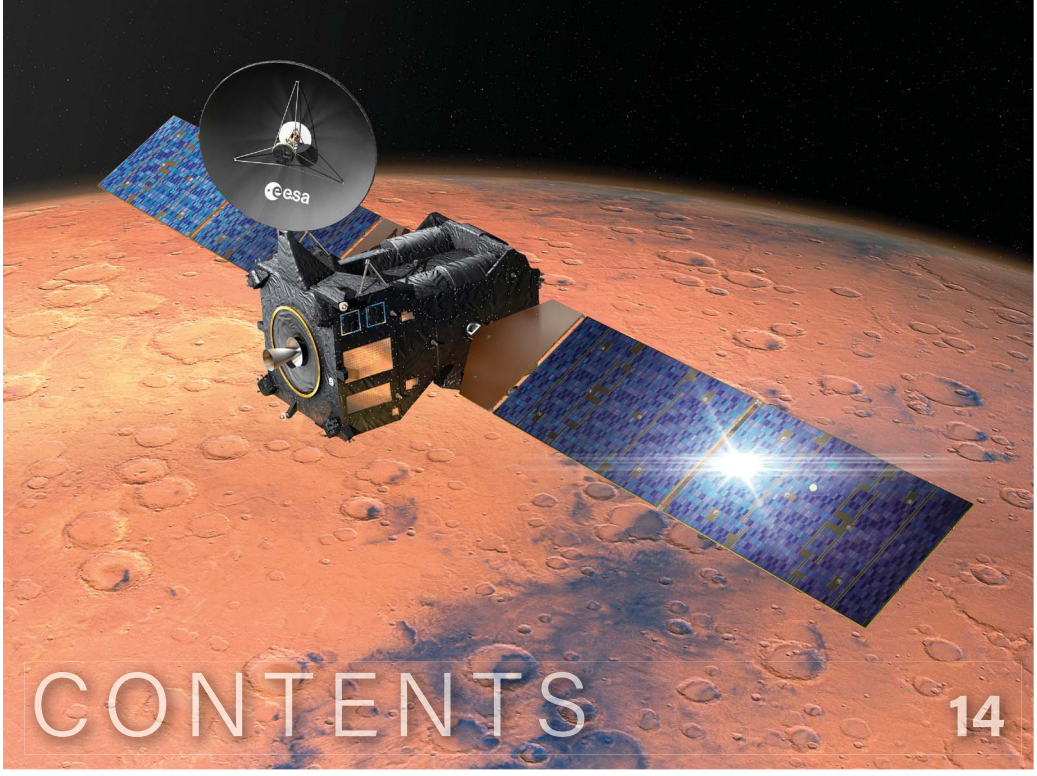

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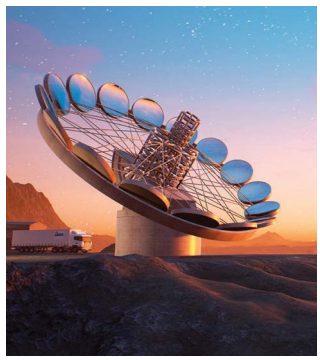

ON THE COVER

With a unique design that uses a ring of primary mirrors, the ExoLife Finder could help us explore the universe as never before. IMAGE COURTESY OF LIOM AND THE INSTITUTO DE ASTROFÍSICA DE CANARIAS (IAC)

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Searching for life

What do Vampire Weekend, The Flaming Lips, and this full-scale model of the James Webb Space Telescope have in common? All were mobbed by crowds in appearances at the 2013 edition of the South by Southwest festival in Austin, Texas. NASA/CHRIS GUNN

In early 2013, when I left graduate school and went into journalism, I felt sure that we were on the brink of finding life beyond the solar system. In particular, red dwarf stars were a clear opportunity: They are small and intrinsically dim, which makes it easier to study the planets they host. The James Webb Space Telescope (JWST) was several years away from launching, but there was hope that it could detect biosignatures — gases caused by life.

It hasn't panned out that way. Red dwarfs' high levels of magnetic activity produce monstrous flares and star spots that make it challenging to analyze data and hard for small planets to retain atmospheres. A 2025 review in *Proceedings of the National Academy of Sciences* led by MIT's Sara Seager concluded "with the sobering realization that with JWST we may never be able to *definitively* claim the discovery of a biosignature gas in an exoplanet atmosphere."

It's not JWST's fault — it wasn't even meant to study exoplanets. It was conceived to corral faint infrared light from the early universe, not look at bright, nearby stars and tease out a planet amid the glare. Through the efforts of scientists like Seager in the 2000s, JWST's instruments were redesigned so that they could study exoplanets, but the telescope is not purpose-built for that task.

On page 18, Thomas Villa reports on a telescope in development that is — the ExoLife Finder (ELF), featuring a radical design that exploits physics to cancel out the light of a host star. It's an ambitious project, with plenty of technical challenges to overcome. But a smaller version to test the concept could break ground within a year.

JWST still has a crucial role to play, as it could identify candidates for follow-up study. But it appears increasingly likely that it will be the next generation of telescopes that has the first realistic chance to make a definitive detection of a biosignature on an exosolar planet. Perhaps that telescope will be ELF.

I hope you enjoy the story.

Mark Zastrow
Editor-in-Chief

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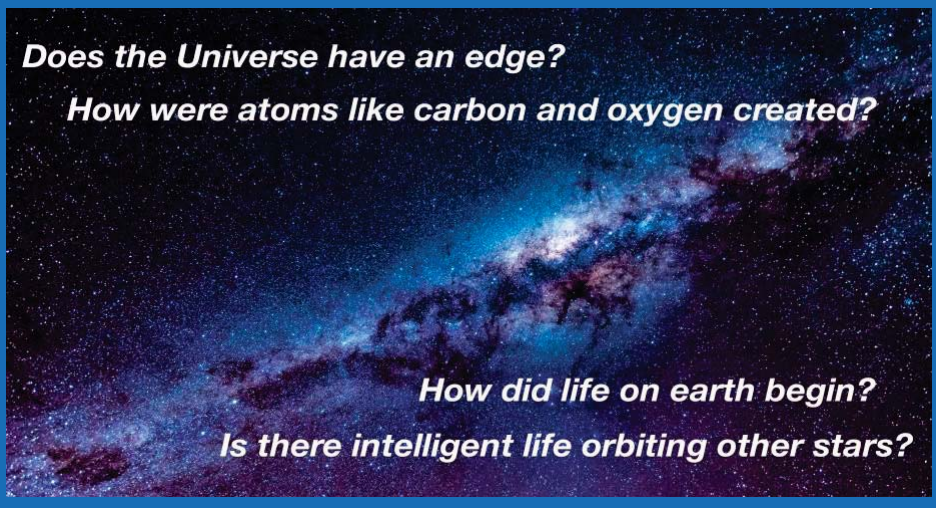
Does the Universe have an edge?
How were atoms like carbon and oxygen created?
How did life on earth begin?
Is there intelligent life orbiting other stars?

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7. Star mass, star lifetimes, the creation of neutron stars and black holes, and the creation of elements from star explosions.
8. Pulsars, telescopes, adaptive optics, space telescopes, and telescope arrays.
9. Enjoying the night sky, galaxy classification, star clusters, active galactic nuclei, and synchrotron radiation.
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11. Special and general relativity, gravitational red shift, black holes, and the cosmic microwave background.
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15. Are there extraterrestrial civilizations on Earth? What is the evidence? Are the witnesses reputable?
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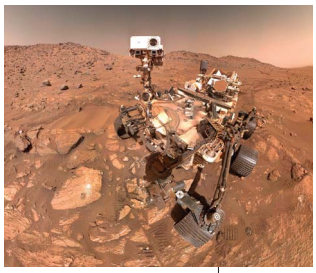

Selfies of rovers like Perseverance can appear "hands-free" because they're created from many shots stitched together.
NASA/JPL-CALTECH/MSSS

We welcome your comments via email to **astronomyeditorial@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

A pic beyond description

There are no words in the English language to describe the distance of Abell 3667 from Earth: 700 million light-years is a number so large as to be beyond our ability to comprehend it. Words like *unimaginable*, *gigantic*, *unbelievable* do not do justice to the fact of its distance from our planet. The ability to photograph it — as seen on page 7 of the December 2025 issue — boggles the mind! **—Bob McRann**

Selfie secrets

In the January 2026 issue, page 8, you show a selfie of the Mars rover. The rover appears to be completely separated from the camera, so how did it take the photo? **—Robert Bobo**

Senior Editor Alison Klesman responds: *There are two reasons why the arm holding the camera is never seen when a rover like Curiosity or Perseverance takes a selfie. First, think about how you take a selfie with a phone: You hold the camera out with your arm extended, and your arm doesn't appear in the selfie because it is below or behind the view of the lens. Similarly, in many cases Perseverance's arm is outside the field of view.*

Admittedly, it's a bit more complicated for a rover to take a selfie than for a human. For humans, selfies are one step: Snap a pic and we're done. But Perseverance's camera can't capture the entire rover in a single shot, even from the end of its 7-foot-long (2.1 meters) arm. Instead, the rover must take dozens of photos to fit its entire body and background into the view. In some of these raw shots, portions of the arm may be visible, but the rover takes so many images that when NASA staff stitch them together into a final, single selfie, they can choose to use the sections of the images without the arm.

Super interesting, super clear

Just wanted to say that I thoroughly enjoyed Brooks Mendenhall's article on SN 2023zkd (January 2026), which was fascinating and informative. Not only did his article cover the sensational teamwork involved in the discovery and analysis of this supernova anomaly, but he also quickly explained standard type II supernovae in such a way that could be easily followed. Good on him, and on *Astronomy*! **—Aaron McKenzie,** Fair Oaks, CA

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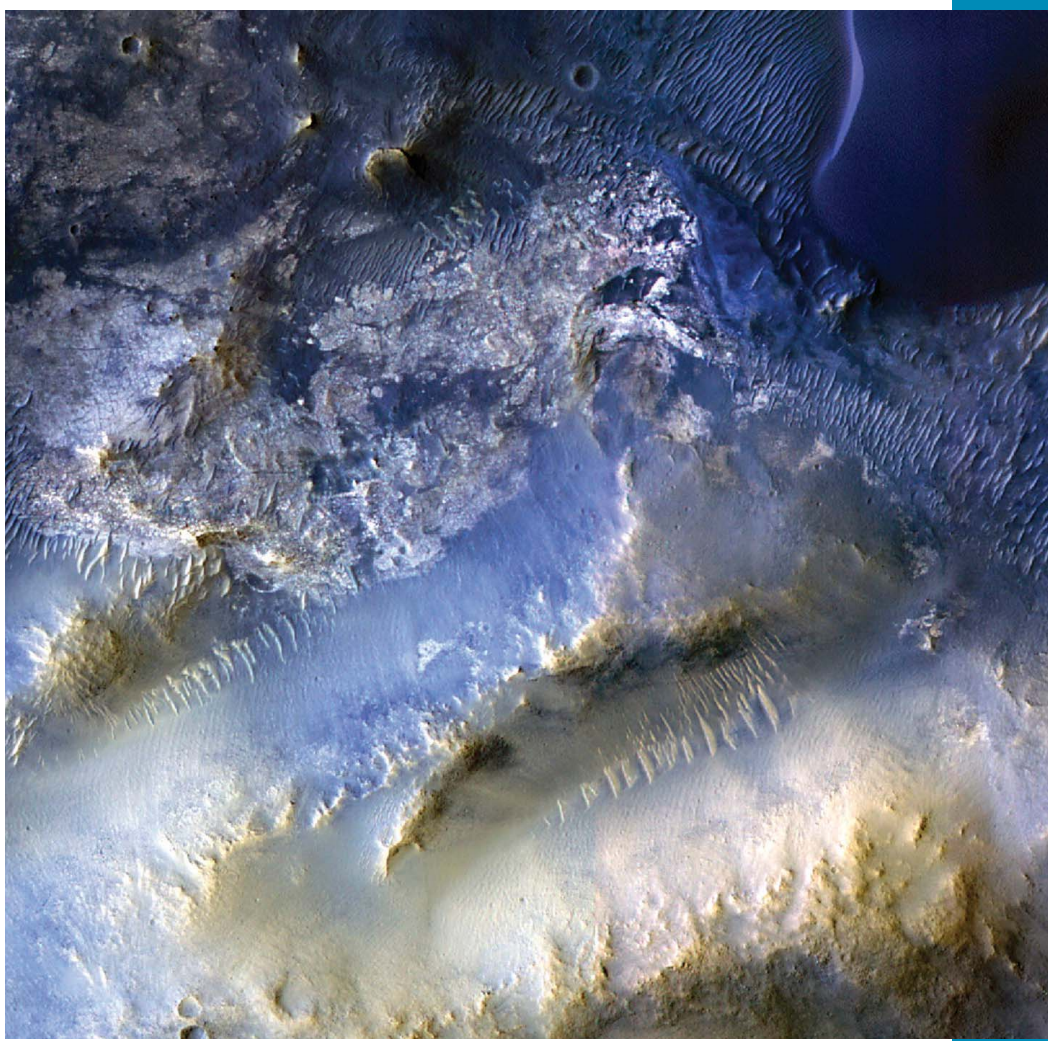
Landmark photo shows dunes and plains of Mars.



On Oct. 7, the powerful High Resolution Imaging Science Experiment (HiRISE) camera aboard NASA's Mars Reconnaissance Orbiter (MRO) captured its 100,000th image of the Red Planet. The stunning shot shows a portion of Syrtis Major, a famous dark surface feature just north of the equator. The plains and dunes visible here were imaged in two different filters, providing color information. Regions with more sand and rock (and less dust) appear bluer. Long known to vary in appearance, Syrtis Major's ever-changing landscape is sculpted by blowing winds, which sweep the sand up into dunes.

MRO has been circling Mars since 2006. Its data helps us better understand the dynamics of the Red Planet, including the challenges future astronauts may face there. HiRISE's targets — including this one — are largely chosen by the general public. You can suggest a target at www.uahirise.org/hiwish.

—ALISON KLESMAN

NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA. BOTTOM FROM LEFT: NASA, ESA, STSCI; SNOLAB; NASA/JPL/SPACE SCIENCE INSTITUTE

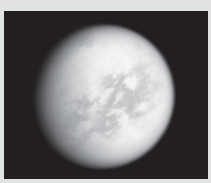
HOT BYTES

SATELLITES CROWD OUT SCIENCE

A Dec. 3 *Nature* study based on the number of launches for proposed megaconstellations found that by the end of the 2030s, Earth could be orbited by half a million satellites. Their trails could contaminate over 96 percent of images from space-based telescopes, including Hubble.

IT'S SNO COINCIDENCE

The SNO+ detector at the underground Sudbury Neutrino Observatory in Canada has spotted a never-before-seen reaction in which solar neutrinos — elusive particles that rarely interact with matter — struck carbon atoms and turned them briefly into nitrogen atoms.

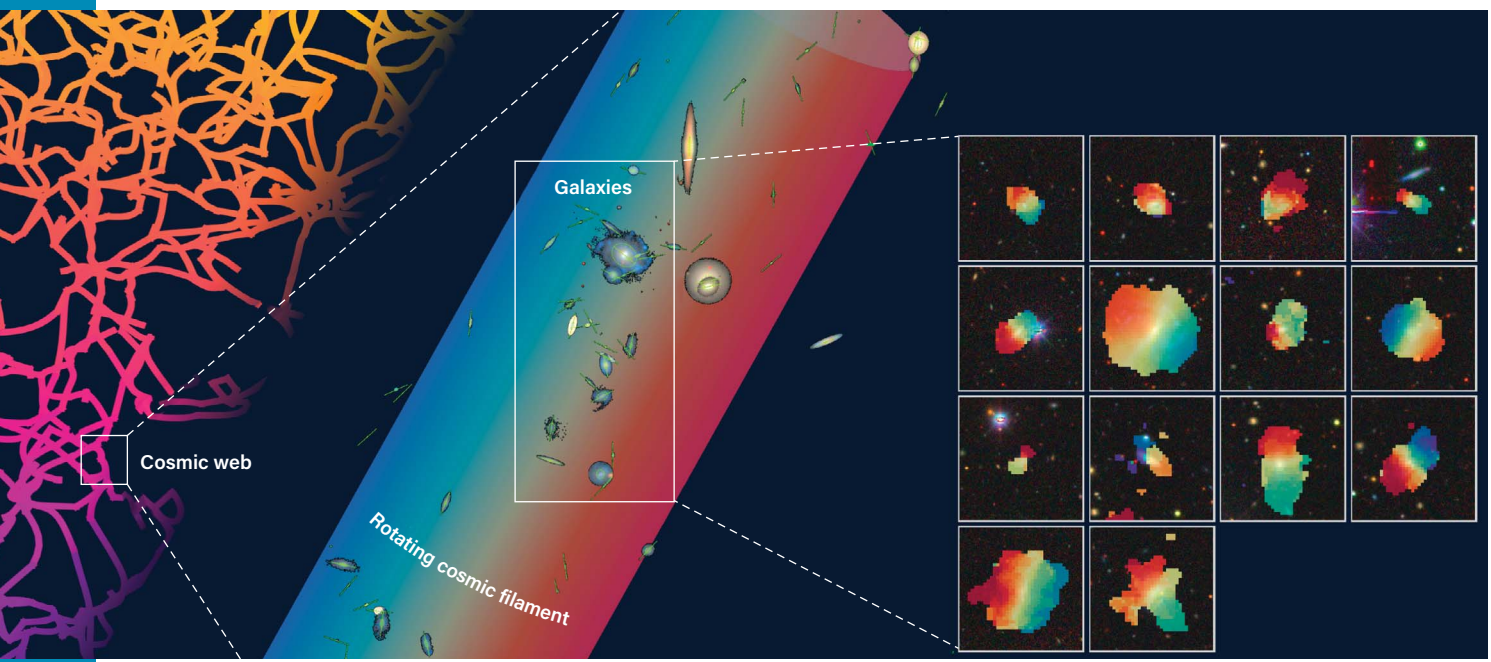


A TITANIC SLUSHY

Since 2008, astronomers have thought that Titan, the largest of Saturn's moons, housed a subsurface liquid ocean. But a reanalysis of Cassini data showing how Saturn's gravity stretches the moon suggests that the interior is slush — not quite liquid and not quite ice.

A GIANT SPINNING GROUP OF GALAXIES

Fourteen galaxies are whirling together within a twirling segment of the cosmic web.



TWIRLING TOGETHER. This illustration shows a tangle of cosmic web filaments at left. At center is depicted the rotating filament of hydrogen identified by the team, as well as the 14 galaxies within it. At right are maps of the motion of neutral hydrogen in the galaxies, showing their individual direction of rotation. Blue is motion toward us and red is motion away. LYLA JUNG (CC BY 4.0)

» Astronomers have just spotted one of the biggest spinning structures ever seen. Some 424 million light-years away, a string of 14 galaxies spanning 5.5 million light-years is rotating together, embedded within a gyrating chunk of the cosmic web — the large-scale network of gas strung throughout the universe. The find was published Dec. 4 in *Monthly Notices of the Royal Astronomical Society*. Such synchronized alignments are unexpected and could complicate analysis of major upcoming surveys.

ROUND AND ROUND

Scientists found the structure in data from South Africa's MeerKAT radio telescope. Observations by the Dark Energy Spectroscopic Instrument and Sloan Digital Sky Survey revealed more details. They saw that members on one end of the galaxy string were moving toward us, while those on the other end were moving away. Using the galaxies' motion to model the filament's overall rotation, they determined that outside of its central spine, the bulk of the filament is racing around at some 250,000 mph (400,000 km/h).

The galaxies in this structure are brimming with neutral hydrogen, the raw material for star formation. Because hydrogen is easily disturbed, it acts like a tracer, revealing the flow of gas and momentum. That makes this filament a live demo of how galaxies grow, acquiring material and spinning up over time.

What struck the team as particularly odd is that most of the galaxies are also rotating around their own central axis in the same direction that the filament in which they're embedded is spinning. Astronomers generally think the direction galaxies rotate is random. But in this case, "we believe this [rotational alignment] is caused by the gravitational interaction between the galaxies and the filaments," says Madalina Tudorache, a postdoctoral research assistant at the University of Oxford, who led the study. More specifically, she says, the filament is imparting its rotation on the galaxies via "a transfer of angular momentum." This provides important clues, she says, to how a galaxy's environment affects its formation and evolution.

COSMIC CONTAMINANT

Giant spinning structures such as this could throw a wrench into cosmological surveys such as those planned with the Vera C. Rubin Observatory and

the European Space Agency's Euclid mission. These projects study dark matter and the universe's expansion by exploiting the fact that light from cosmic objects is bent along its journey to Earth by the gravity of matter it passes. This phenomenon, called weak lensing, has a faint funhouse mirror effect that can make galaxies appear to be aligned, so astronomers use apparent alignments to identify weak lensing and map where unseen matter might be hiding. But if galaxies are *actually* aligned — such as through interactions with the cosmic web — it could produce a false signal, making our maps incorrect.

"The alignment between galaxies within filaments (or other cosmic structures) breaks our assumption that without gravitational lensing, all galaxies are randomly orientated," says Naomi Robertson, a postdoctoral research associate at the University of Edinburgh, who was not involved in the study. "So we need to account for this effect when we make predictions for what our lensing measurements should look like."

Robertson says observations like this give astronomers a chance to test how they will analyze incoming data from Rubin and Euclid to map the cosmos. Additionally, she says, combining those surveys with other datasets will allow astronomers to more fully explore the cosmic web. – ASHLEY BALZER VIGIL

Roman Space Telescope construction complete

ON NOV. 25, engineers at NASA's Goddard Space Flight Center successfully joined the two main segments of the Nancy Grace Roman Space Telescope, officially completing construction of the observatory ahead of schedule. In this photo, technicians watch as the two halves of the telescope are joined; the large, dark solar panels are visible above the silver back end of the telescope assembly and spacecraft bus. Although Roman has a primary mirror the same size as Hubble (2.4 meters), its 288-megapixel Wide Field Instrument boasts a field of view 100 times larger. This capability will power surveys that study dark matter, transient astronomical events, and the universe's expansion. While the mission is formally scheduled to launch by May 2027, a Dec. 4 NASA press release cited a potential liftoff in fall this year aboard a SpaceX Falcon Heavy. The completed telescope is now undergoing a final gauntlet of tests before it is moved to NASA's Kennedy Space Center in Florida this summer, where it will be prepped for launch. – BROOKS MENDENHALL

NASA/JOLEARRA TSHITEYA

QUICK TAKES

ISAACMAN'S VISION

In a Dec. 19 town hall, new NASA administrator Jared Isaacman pledged to prioritize U.S. space exploration, establish a permanent presence on the Moon, and support a self-sustaining orbital economy driven by private-sector breakthroughs in biotech and pharmaceuticals.

GARBAGE GAME PLAN

Hundreds of millions of dangerous debris fragments currently speed through space with no financial incentive to clean them up. An Oct. 5 study using game theory proposed a win-win solution where a regulatory body collects fees from satellite operators and redistributes them to debris remediators.

CUTTING-EDGE SOLAR MAP

Using Parker Solar Probe data, scientists from the Harvard–Smithsonian Center for Astrophysics created the first 2D map of the Sun's Alfvén surface — the edge of a star's atmosphere where solar winds outpace the star's magnetic grasp and enter interplanetary space — to better understand how space weather impacts Earth.

REUSABILITY RACE

In China's first efforts to replicate the reusability of SpaceX's Falcon 9, the commercial LandSpace Zhuque-3 and state-run Shanghai Academy of Spaceflight Technology Long March 12a rockets successfully reached orbit during inaugural test flights in December 2025. But both missions ended with failed booster landing attempts.

HERE WE GO AGN

AI-assisted modeling of data from the Euclid space telescope indicates that the supermassive black holes in galactic centers are two to six times more likely to be actively feeding on matter — so-called active galactic nuclei (AGN) — when their host galaxies are colliding and merging.

THEORY BLOWN AWAY

Starlight and stardust are not powerful enough to drive the winds of giant stars, which transport metals through our galaxy, according to a study published Nov. 27 in *Astronomy & Astrophysics*, overturning a long-held idea about how the atoms needed for life spread. – B.M.

A star goes superkilonova

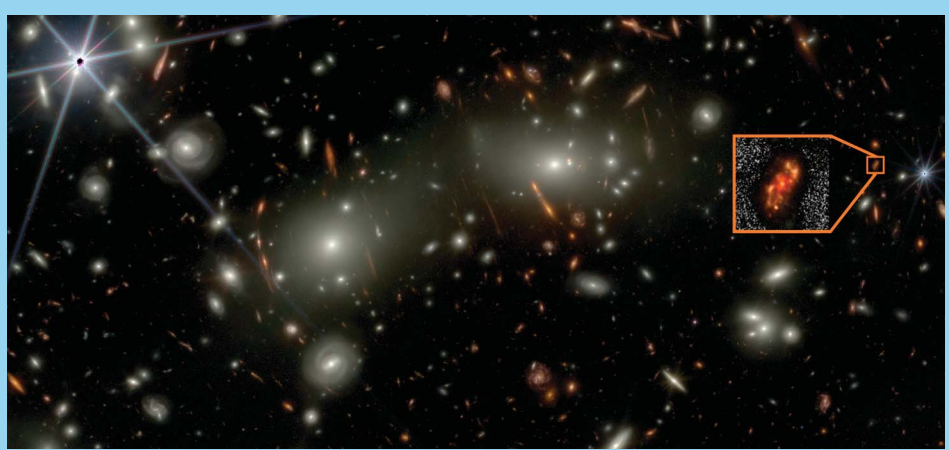
IN AUGUST, astronomers saw both light and gravitational waves from an event they are calling a possible superkilonova, where a supernova and kilonova occur almost simultaneously. A supernova is the explosion of a massive star at the end of its life. A kilonova is a rarer event where two neutron stars, or a neutron star and a black hole, collide. These mergers send gravitational waves rippling through space-time and produce a characteristic fading red glow as they forge heavy elements like gold and platinum. In a superkilonova, when a rapidly spinning massive star goes supernova (at left in this artist's rendering), it creates not one but two neutron stars (center). These objects spiral together and merge almost instantly in a kilonova (right). Visible is both the red glow from the kilonova, as well as the bluer glow of lighter elements (hydrogen and helium) from the supernova collapse of a massive star's core. The kilonova occurs in the immediate aftermath of the star's collapse, yet is partially obscured by the larger supernova explosion. This explains why the observed light from the kilonova brightened and deviated from the typical reddening after a few days, revealing the spectral signatures of hydrogen and helium. – B.M.

CALTECH/K. MILLER AND R. HURT (IPAC)

A GRAND DESIGN SPIRAL THAT SHOULDN'T EXIST

Grand design galaxies are similar to the Milky Way, displaying well-formed spiral arms. Astronomers have long thought it takes billions of years to organize such structure. Apparently not: At right in this James Webb Space Telescope (JWST) image is a galaxy remarkably similar to our Milky Way, but seen at a time just 1.5 billion years after the Big Bang. Co-discoverers Rashi Jain and Yogesh Wadadekar, of the National Centre for Radio Astrophysics in Pune, India, named it Alaknanda after the Himalayan river. (The Alaknanda is one of two headstreams of the Ganges River, alongside the Mandakini, which is also the Hindi name for the Milky Way.)

Alaknanda lies behind the massive galaxy cluster Abell 2744, whose gravity bends and magnifies Alaknanda's light, allowing JWST to capture the spiral structure in stunning detail. The galaxy has two sweeping arms wrapped around a bright, round core about 30,000 light-years across. It is forming stars at a rate 20 times faster than the Milky Way, with half its suns birthed in only 200 million years. "Somehow, this galaxy managed to pull together 10 billion solar masses of stars and organize them into a beautiful spiral disk in just a few hundred million years," said Wadadekar in a press release. "That's extraordinarily fast by cosmic standards, and it compels astronomers to rethink how galaxies form." – MICHAEL E. BAKICH



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Pulsar planet defies explanation

SCIENTISTS USING the James Webb Space Telecope (JWST) uncovered a strange exoplanet orbiting a pulsar — a rapidly rotating neutron star left after a massive star's death. Called PSR J2322–2650 b, the world orbits every 7.8 hours at a distance of 1 million miles (1.6 million kilometers). It has a mass similar to Jupiter, but an exotic helium- and carbon-dominated atmosphere never before seen. The find was published Dec. 16 in *The Astrophysical Journal Letters*.

"This system is unique because we are able to view the planet illuminated by its host star, but not see the host star at all," said study co-author Maya Beleznay, a graduate student at Stanford University, in a press release. The pulsar emits mostly high-energy particles, which JWST's infrared sensors cannot see. "So … we can better study this system in more detail than normal exoplanets."

But "instead of finding the normal molecules we expect to see on an exoplanet — like water, methane, and carbon dioxide — we saw molecular carbon," said lead author Michael Zhang of the University of Chicago. At these temperatures, carbon can only dominate if there is no oxygen or nitrogen, which bind to it. So far, molecular carbon hasn't been found in any other planetary atmosphere.

Although the pair resembles a black widow system, which involves a pulsar and a low-mass companion star, PSR J2322–2650 b is the mass of a planet. "Did this thing form like a normal planet? No, because the composition is entirely different," said Zhang. And it can't be the leftover core of a stripped star, he said, because stars don't make pure carbon. "It seems to rule out every known formation mechanism."

"It's nice to not know everything," said co-author Roger Romani, of Stanford and the Kavli Institute for Particle Astrophysics and Cosmology, and one of the preeminent experts on black widow systems. "It's great to have a puzzle to go after." — M.E.B.

WEIRD WORLD. The pulsar planet PSR J2322–2650 b, depicted at left in this artist's concept, is stretched into the shape of a lemon by gravity from its host star, a pulsar (at upper right). It also hosts a strange, never-before-seen atmosphere. ILLUSTRATION: NASA, ESA, CSA, RALF CRAWFORD (STSCI)

PERFECT STORM. A study using the microphone aboard NASA's Perseverance's rover, pictured here, detected 55 bursts of sound that researchers believe are static discharges associated with lightning. The small zaps are generated by friction between dry dust particles in the martian air. NASA/JPL-CALTECH/CNES/CNRS/LANL

Perseverance hears lightning on Mars

IN A STUDY PUBLISHED NOV. 26 in *Nature*, researchers reported what they think is the first evidence of electrical activity in the martian atmosphere.

Unlike Earth's cloud-spanning lightning bolts, lightning on Mars is smaller in scale and caused by friction between dry dust particles. This is akin to the small static charges that build up when you drag your socks across carpet, called triboelectric charging.

Since Perseverance landed in February 2021, its SuperCam instrument has been recording the sounds of the martian atmosphere with its onboard microphone. Across nearly 29 hours of data, researchers found 55 bursts of sound that they suspect are the snaps and crackles of static electricity. All but one occurred during high winds, and 16 were captured during direct encounters with dust devils as they passed over the rover. Thirty-five other instances occurred as storm fronts moved through the area, bringing strong, convective winds that lift dust from the surface.

Perhaps most tellingly, seven of the recordings also included a spike *before* the sound of the discharge arrived, as the lightning interfered with the instrument's electronics. The team replicated this signature in lab experiments on a working duplicate of the SuperCam instrument.

Interestingly, the data showed no seasonal increase in electrical activity when the martian atmosphere is dustiest. The authors argue that the lack of sunlight prevents the surface from warming, starving the atmosphere of the energy necessary for the storms that cause triboelectric charging. This suggests electrical activity is driven more by local dust lifting via storms and dust devils than by the simple presence of dust in the atmosphere.

Though small, these zaps are strong enough to trigger chemical reactions that produce chlorates and perchlorates, which can break down organic molecules. This could explain the puzzlingly rapid destruction of methane in the martian atmosphere, which has been spotted on the ground but not higher in the atmosphere. By shaping conditions near the surface, this process could place constraints on the Red Planet's past and present habitability. — B.M.

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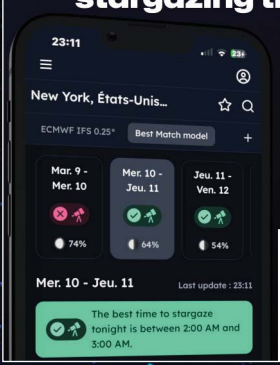

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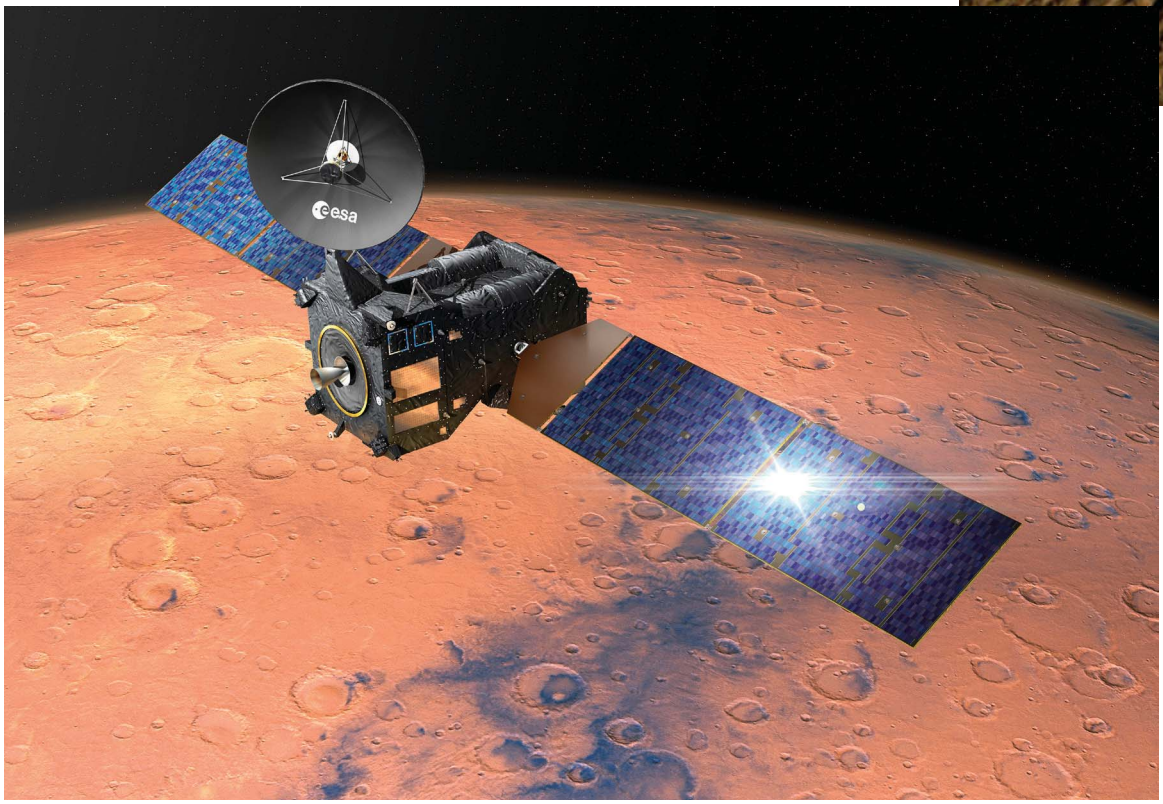
A NEW SPIN ON MARS

A survey of 1,039 twisters propelled by record-fast surface winds is forcing scientists to rethink the Red Planet's climate.

BY BROOKS MENDENHALL



ABOVE: This 12-mile-high dust devil was captured by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter in March 2012. NASA/JPL-CALTECH/UNIV. OF ARIZONA

LEFT: The ExoMars Trace Gas Orbiter (TGO), imagined here in an artist's impression, launched in 2016 to search for evidence of atmospheric gases in the martian atmosphere. A new study used images from the TGO to measure the speed of martian winds. ESA-D. DUCROS, ESA STANDARD LICENSE

FOR TWO DECADES, images from two European spacecraft have contained seemingly mundane digital glitches as they photographed Mars — smears of color from fast-moving dust devils too quick for the camera. Now, scientists have turned those artifacts into a surprising insight. By analyzing 1,039 of these glitches, they have revealed that the winds kicking up dust in Mars's lower atmosphere are far more powerful and common than previously believed.

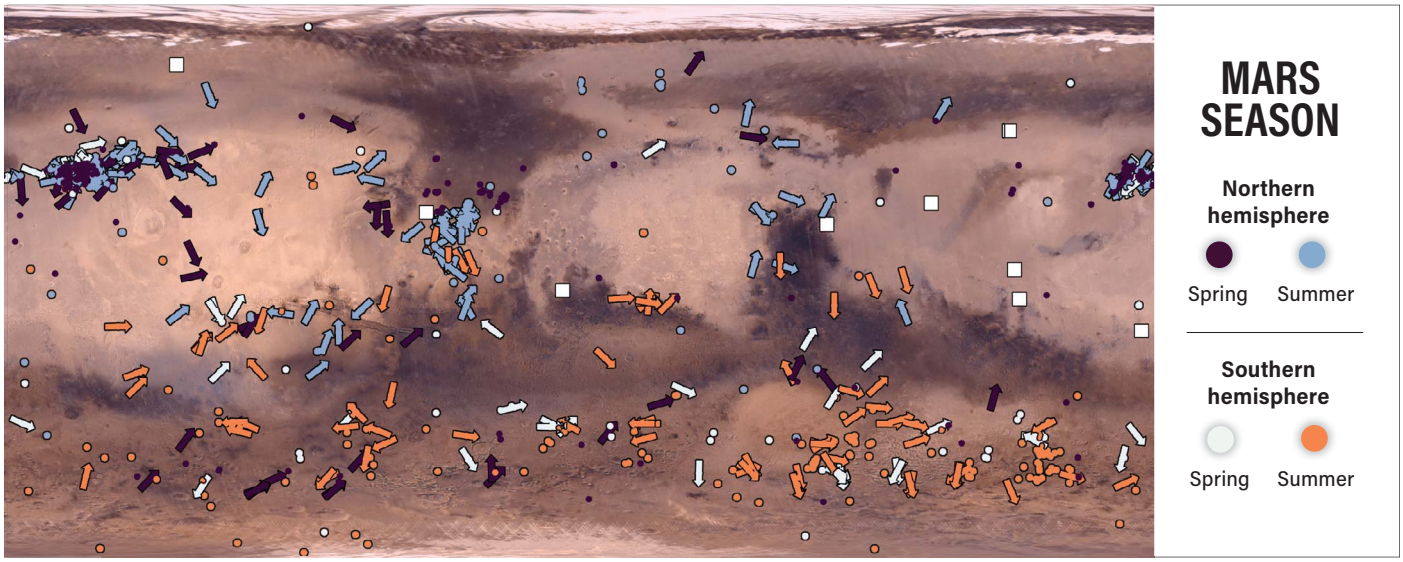
The study, published Oct. 8 in *Science Advances*, reports that these whirlwinds race across the martian landscape at speeds far greater than previously known. The findings not only advance our understanding of Mars' climate but could also prove critical for planning future robotic and human missions by improving forecasts of potentially deadly wind and dust storms at landing sites.

"Dust affects everything on Mars — from local weather conditions to how well we can take images from orbit," said Colin Wilson, a project scientist for Mars Express and ExoMars Trace Gas Orbiter (TGO), in an Oct. 8 press release. "It's difficult to understate the importance of the dust cycle."

Turning noise into a signal

The discovery was made possible by exploiting data from two European Space Agency (ESA) missions whose primary goals were unrelated to dust devils. The veteran Mars Express orbiter has been studying the planet's atmosphere, surface, and subsurface since 2004. The more recent ExoMars TGO, which arrived in 2016, is on a mission to detect small amounts of atmospheric gases that could be signs of geologic or biological processes. Neither was designed to measure wind.

But, thanks to a quirk in their imaging instruments, that's exactly how the team used them. The Colour and Stereo Surface Imaging System (CaSSIS) on the TGO orbiter and the High-Resolution Stereo Camera (HRSC) on the Mars Express both build a single picture by combining views from different channels, which are captured with a slight delay between them. For a static scene, this process is seamless. For a moving object like a dust devil, the delay creates a "color offset" in the final image — a faint digital glitch.



Active dust devils pepper the martian surface during spring and summer, as shown in this map compiled from Mars Express and ExoMars TGO data. The colored dots indicate 1,039 dust devils for which we have only location information, and the arrows indicate 373 dust devils for which we also have speed and direction of motion information. The white squares show the locations of Mars rovers and landers. EXOMARS TGO DATA: ESA/TGO/CASSIS; MARS EXPRESS DATA: ESA/DLR/FU BERLIN; BACKGROUND: NASA VIKING COLOR MOSAIC, CC BY-SA

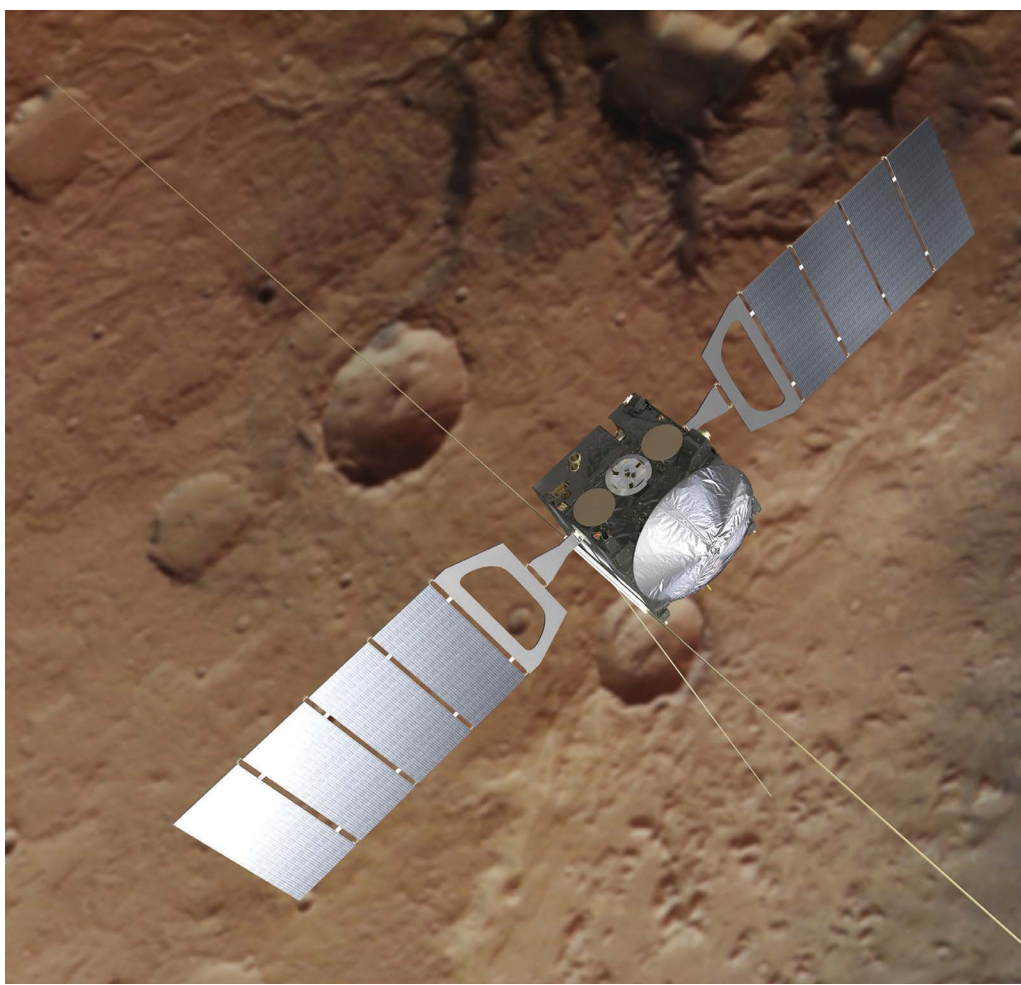
To analyze the vast amount of data, the team trained a neural network to scan the instruments' archives and identify the whirlwinds revealed by the offsets. The glitch, once considered noise, became the signal. "We turned image noise into valuable scientific measurements," Valentin Bickel, postdoctoral fellow at the University of Bern, who led the study, noted in the press release. By measuring the precise distance of the color smear and comparing it to the known, subsecond time delay between the image channels, the team could calculate the dust devil's exact speed and direction of travel.

Rethinking the Red Planet's climate

The movements of martian dust devils are a window into understanding the lower levels of the martian atmosphere. Near-surface winds on Mars not only push dust devils across the surface, but also lift surface dust and inject it into the atmosphere, which drives the planet's dust cycle — a key player in Mars' overall climate. Before this study, scientists relied on limited data from rovers and indirect observations, like tracking cloud movements, to help build computer simulations called global circulation models (GCMs). The primary martian model, the Mars Climate Database (MCD), has long been the standard for predicting the planet's weather.

This new survey, however, reveals a significant gap between the models and real-world observations. The study found that the MCD models "systematically underestimate" the true, near-surface wind speeds in 76 percent to 96 percent of cases.

This, in turn, affects our understanding of Mars' dust cycle. Scientists have a baseline for the nonvortical (not from a vortex like a dust devil) force required to lift dust and inject it into the atmosphere: about 51 mph. According to predictions



made using the MCD model, only 6 of the 1,039 observed dust devils should be propelled by winds strong enough to meet this so-called "wind stress threshold."

The new, direct measurements show that 124 of the dust devils actually exceeded the threshold, with winds as high as 98 mph (157 km/h) pushing the dust devils along. This indicates that nonvortical dust-lifting winds are far more common than the models predicted. Mars' atmosphere is so thin — roughly 1 percent the density of Earth's — that a human would barely feel such a strong wind, but the new data indicates these winds are more than capable of kicking up the dust that defines the global climate. This also means that in certain regions, far more dust is being lofted into the atmosphere than scientists previously understood.

A planet-wide weather map

While rovers and landers have given us glimpses of martian dust devils for years, our knowledge was confined to a few specific locations. This new research provides a sweeping, planetwide view. "Dust devils make the normally invisible wind visible," said Bickel in the press release. "By measuring their speed and direction of travel, we have started mapping the wind all over Mars' surface."

The resulting map shows that while dust devils appear all over Mars, many form in specific regions, including the vast plains of Amazonis Planitia and Lunae Planum, and prominent areas like Tharsis and Chryse Planitia. The study points to these areas as critical sources for atmospheric dust.

This information will help scientists forecast dangerous planet-encircling dust storms — the kind that ended the mission of NASA's Opportunity rover in 2018 — by showing them where these storms are most likely to form. It is also effectively the first data-driven hazard map for Mars explorers, giving planners the opportunity to steer high-priority robotic and human missions away from these high-wind zones and protect critical solar panels and habitats from being blasted by martian dust.

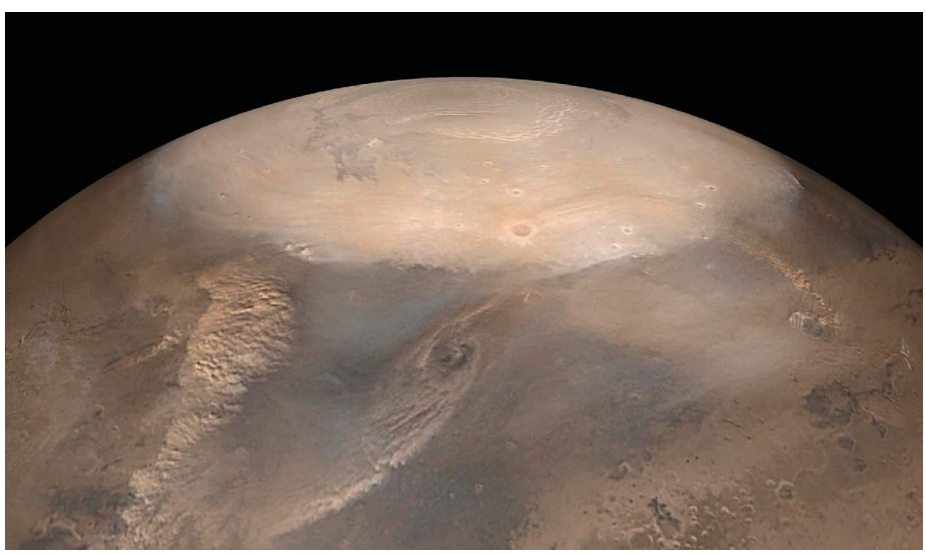
The new understanding of Mars's weather is already having a practical effect on mission planning. Information from the growing dust devil catalog is helping to plan the 2030 landing of the ExoMars Rosalind Franklin rover, to ensure it touches down outside of the planet's global dust storm season.

Brooks Mendenhall *is a staff writer at* Astronomy *magazine and is based in Chattanooga, Tennessee.*

FAR LEFT: The Mars Express flies over the martian landscape in this artist's impression. Images taken by the spacecraft's High-Resolution Stereo Camera (HRSC) were used in a new study to measure wind speeds on the Red Planet. SPACECRAFT: ESA/ATG MEDIALAB; MARS: ESA/DLR/FU BERLIN, CC BY-SA 3.0 IGO

LEFT: The Colour and Stereo Surface Imaging System (CaSSIS) on board ESA's ExoMars Trace Gas Orbiter (TGO) captured these three dust devils tracking across the martian surface on Nov. 8, 2021. ESA/TGO/CASSIS, CC BY-SA

BELOW: Springtime on Mars is a turbulent season. This 2002 composite from the Mars Global Surveyor captures the swirling clouds of at least three dust storms near the martian north pole. As the polar cap's frozen carbon dioxide thaws, the clash between the retreating ice and the warming ground whip up visible dust storms, like those seen here. NASA/JPL/MALIN SPACE SCIENCE SYSTEMS



COULD THIS FIND LIFE ON ALIEN

TELESCOPE WORLDS?

The ExoLife Finder has a radical design to dim a star's light and map the surface of its planets. BY THOMAS VILLA

THE EXOLIFE FINDER (ELF) looks like no telescope ever built. A spectacular crown of 15 five-meter mirrors perches atop a sprawling metal lattice, resembling petals on a 10-story-tall mechanical flower — more sculpture than observatory. It is a fundamentally new type of telescope, one that its designers say could discover life on Earth-like planets beyond our solar system.

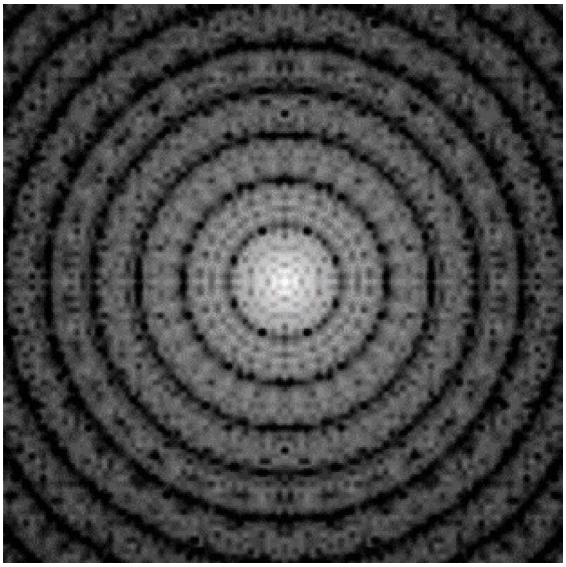
The radical design is the brainchild of astrophysicist Jeff Kuhn of the University of Hawai'i. For now, it exists only in renderings. To build it, Kuhn and the team he's assembled must first develop and perfect techniques and technologies never before used in astronomy.

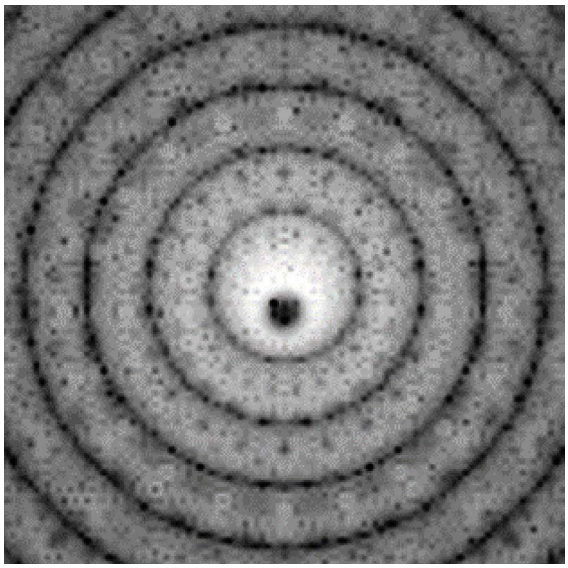
ExoLife Finder is imagined here as a 35-meter-diameter array of smaller mirrors, supported by a complex structure of wires that perfectly balances so that the elements hold each other up. Its unique design will allow astronomers to combine the light from the mirrors in such a way to block the glare of a star and directly image the faint planets around it.
IMAGE COURTESY OF LIOM AND THE INSTITUTO DE ASTROFÍSICA DE CANARIAS (IAC)

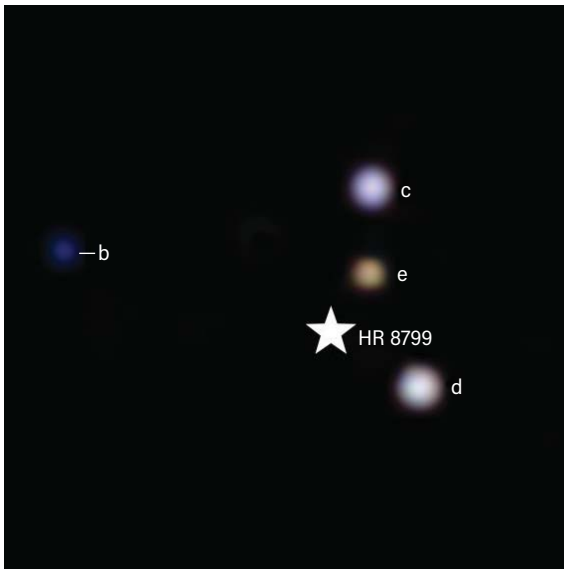
That ring of mirrors, working in sync, would use a cutting-edge technique — the equivalent of stellar noise canceling — to block out the glare of a host star so it can capture images of orbiting worlds. If it works, it could monitor planets, create surface maps, and possibly even detect heat given off by life-forms or their technology.

"For a long time, it was thought that this [technique] required telescopes in space," says John Mather, the Nobel Prize-winning astrophysicist who led the science team for the James Webb Space Telescope (JWST). "But Kuhn's team showed that it might not be impossible from the ground."

The word *might* is meaningful here. The technical hurdles are high. And in the race to build a telescope that can find a second Earth, there is no shortage of competing ideas. But if the experiment succeeds, it could open the door to a new era of ground-based telescopes — and settle the question of whether we are alone in the universe.







LEFT TOP AND MIDDLE: At top is a simulation of ELF's point spread function — the way an image of a bright star appears when the light from all its mirrors is combined. The mirrors create an image with a lobulated structure that looks almost like a sunflower. Below is the point spread function when all the mirrors are co-phased, or tilted relative to each other such that a dark region of destructive interference occurs (just below center). By placing the star (and its planets) in this "hole" where the starlight is absent, the planet's faint light can be directly observed. KUHN ET AL., *LIGHT: ADVANCED MANUFACTURING* (2025), DOI 10.37188/LAM.2025.033 (CC BY 4.0)

LEFT BOTTOM: Direct imaging of exoplanets is possible today using a coronagraph to physically block out the host star's light. This technique allows us to see large (bright) Jupiter-sized gas giant planets far from their stars; smaller, terrestrial and Earth-like planets remain invisible with current technology. This photo shows HR 8799 b, c, d, and e, as imaged in infrared light by JWST. The host star's location is marked with the cartoon star symbol. NASA, ESA, CSA, STSCI, LAURENT PUEYO (STSCI), WILLIAM BALMER (JHU), MARSHALL PERRIN (STSCI)

Seeing other worlds

The first challenge of imaging any exoplanet is resolution — being able to resolve the planet separately from its host star. All telescopes have a fundamental physical limit: the diffraction limit. This defines how sharp an image the telescope can produce, and it's related to the wavelength of the incoming light and inversely to the size of the mirror. The larger the mirror's diameter, the smaller the diffraction limit and the finer the details it can resolve.

ELF borrows a concept from radio astronomy called interferometry. It will use many mirrors distributed in an array, and combine their light. With specialized optical equipment to combine the beams, extremely careful calibration, and a lot of math, this technique can produce an image as sharp as if it were taken with a single mirror the same size as the widest point of the array, called the baseline. ELF's ring of mirrors is 115 feet (35 meters) across, rivaling the aperture of the largest telescope currently under construction, the 39-meter Extremely Large Telescope in Chile, but leaving out the central mirror segments — and the associated price tag.

"[It's] a great trick. We've used it in radio astronomy for a long time," says SETI pioneer Jill Tarter of the technique, called aperture synthesis. "It's harder in the optical part of the spectrum," she notes — it requires more precise control over the beams of light due to the shorter wavelengths of visible light — "but now they can do it."

But resolution is not the hardest challenge: Astronomers must also suppress the overwhelming light from the host star, so that only the faint reflected light from the planets remains. The smaller the planet, the fainter and more challenging it is to image. So far, the smallest planets we have been able to image are the size of Saturn. Going smaller will require technological advances and the ability to capture scenes with higher contrast.

Think of a performer on stage. They can't see the audience through the spotlights aimed at them. To mitigate this, they might block the glare with a hand in front of their face. Astronomers now routinely do this on ground- and space-based telescopes using an instrument called a coronagraph, which creates an artificial eclipse by placing a physical mask in front of the undesirable light source.

But rather than a physical coronagraph, ELF will use a potentially more powerful technique called nulling interferometry. The idea is to combine the beams from its several mirrors so that they interfere and block out the starlight, without a physical mask.

Anyone who has used noise-canceling headphones knows that even if a new shopping center is going up right next door, you will hear nothing. This is because the headphones analyze the incoming sound waves, identify their crests and troughs, and emit a sound that creates destructive interference. Where a crest

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arrives from outside, the headphones generate a trough; where there is a trough, they generate a crest. The result? A perfectly calm sea of silence.

That principle can be extended to light, which is an electromagnetic wave. ELF will treat the star's light as "noise" to be cancelled out, keeping only the desired signal — the light from its planets.

A star's image in a telescope is not a perfect dot, but a slightly blurred spot with a structure that astronomers call the point spread function. The shape, number, and orientation of a telescope's mirrors and other structures all combine to produce a characteristic diffraction pattern of alternating bright and dark areas in that point spread function. Think of stars in Hubble images, with their sharp X-shaped set of spikes, or the distinctive eight-pointed spikes in JWST photos. These are diffraction patterns. They can be a nuisance — but if your telescope is cleverly designed, they can become a resource.

ELF is designed so that when its beams are combined, they can form a characteristic pattern of self-interference. "The trick is that, if instead of putting all these mirrors exactly in phase [so all the troughs and peaks of the light waves line up] we shift them a little, adding some relative phase between them, we can control things so that destructive interference is generated at a specific point in the image," explains Auxiliadora Padrón Brito, a postdoctoral researcher at the Instituto de Astrofísica de Canarias (IAC).

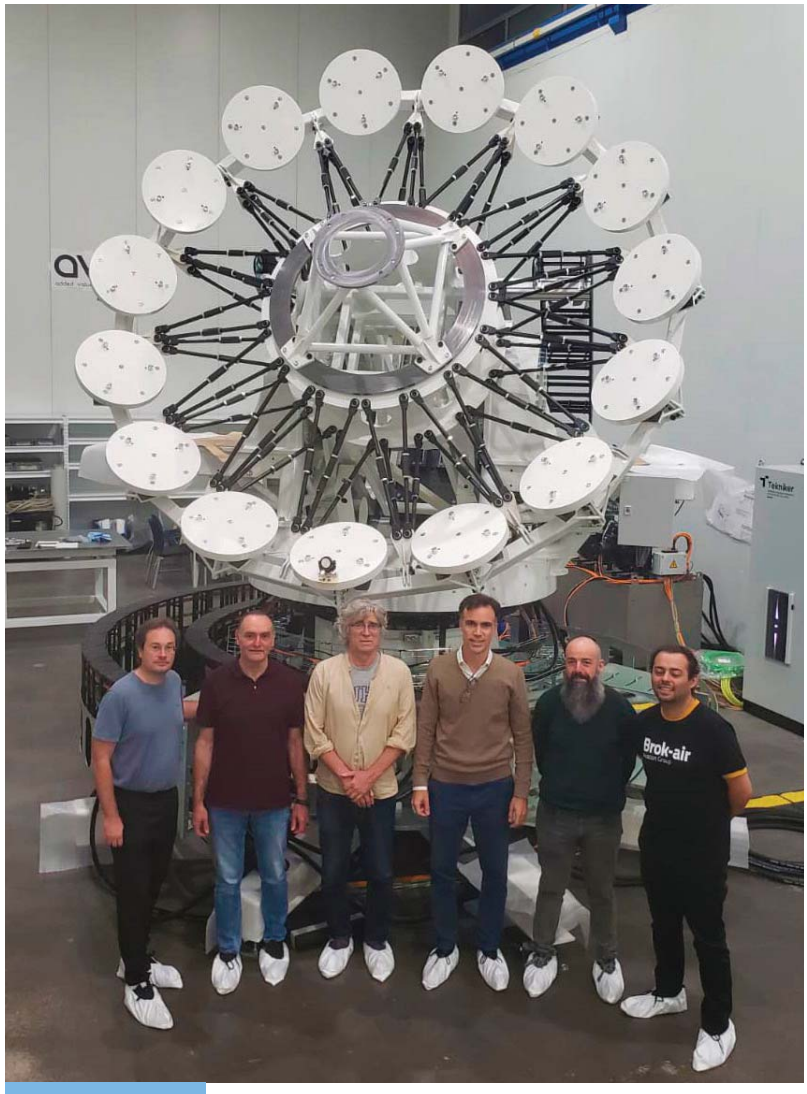
"We can now create and customize the telescope's diffraction pattern, so the telescope itself becomes a coronagraph," Kuhn says. Destructive interference creates a "hole" near the star's position, allowing the fainter light of the planet to shine through.

A new type of telescope

Nulling interferometry was first proposed in 1978 as a technique to image exoplanets by Ronald Bracewell, a radio astronomer and engineer at Stanford University. In the 1990s and 2000s, experiments at the Multiple Mirror Telescope and the Large Binocular Telescope in Arizona and Keck Observatory in Hawaii proved the concept. But implementing it on the scale of ELF is a much more complex problem.

To solve it, Kuhn has assembled a team of around 20 scientists and engineers at the Laboratory for Innovation in Opto-Mechanics (LIOM) in San Cristóbal de La Laguna, Tenerife, in the Canary Islands, that includes top-tier experts as well as young talent. Electronics engineer Diego Tamayo Guzmán and neural-networks specialist Natalia Arteaga Marrero are working on a way to control ELF's mirrors. The 15 primary and 15 secondary mirrors have more than 500 possible degrees of freedom, or independent ways the mirrors can move.

To achieve a coherent image, the primary mirrors must be precisely tuned together "to within tens of nanometers," says Arteaga Marrero. That's smaller than the size of a virus. This tuning must happen quickly, on timescales of about 10 milliseconds.



Several team members pose in front of the completed mechanical structure for the SELF telescope after it successfully passed structural testing in early November 2025. From left to right: Nicolas Lodieu, SELF project scientist; Ricardo Diego Garamendi, Added Value Industrial Engineering Solutions (AVS) president; Jeff Kuhn, LIOM project chair; Sergio Salta, AVS Earth Observation Project management; Jose Antonio González Olivera, TEKNIKER Automation and Control Unit researcher; Diego Tamayo Guzmán, control engineer.
IMAGE COURTESY OF LIOM AND THE INSTITUTO DE ASTROFÍSICA DE CANARIAS (IAC)

This makes ELF so complex that it cannot be treated like a classical telescope, Kuhn says: It must be controlled via machine learning. Additionally, "we need a different way to manufacture mirrors," he says, because the system requires mirrors light enough to move with extreme delicacy and speed.

One of the most promising techniques for this is curvature polishing. Rather than grinding down a slab, "we slightly melt the glass on one side" with a laser, Tamayo Guzmán says, to generate a curvature on the other face. This process can yield lighter and thinner mirrors than traditional methods. "The big job is to figure out how much laser power to apply, for how long, and at which locations … [to] achieve the desired curvature."

Another innovative technique, developed by the French National Centre for Scientific Research (CNRS), is so-called living mirrors, which have a polymer printed on the back. Applying electrical voltage to the polymer changes the mirror's

Kuhn has assembled a diverse team of experts and up-and-coming researchers to turn SELF and ELF into realities. Pictured here are several members. Back row, from left to right: Víctor Quintero, LIOM project manager; Natalia Arteaga Marrero, postdoctoral researcher; Diego Tamayo Guzmán, control engineer; Auxiliadora Padrón Brito, postdoctoral researcher. Middle row, from left to right: Raquel Conde Viera, LIOM communication manager; Jeff Kuhn, LIOM project chair; Adrián Sánchez Chaves, graduate student. Foreground: Nicolas Lodieu, SELF project scientist. IMAGE COURTESY OF LIOM AND THE INSTITUTO DE ASTROFÍSICA DE CANARIAS (IAC)

curvature with more speed and precision than traditional adaptive optics systems that use actuators to deform the mirror. "You can modify it on the fly … depending on what you need at that moment. It's like a new layer of fine control on top of the 500 degrees of freedom we already have," Tamayo Guzmán says.

The team is also looking to lighten the telescope structure itself to reduce costs and make the project feasible. One idea comes from a concept developed by American architect Buckminster Fuller in the 1950s known as tensegrity, a combination of the words *tension* and *integrity*.

Engineers are concerned with two types of stress. Normal stress comes from force that acts perpendicular to a surface. That's exactly what you want when you hammer a nail into a board, striking along the axis of the nail so the force is perpendicular to the wood. When you miss and the nail bends (and maybe your finger gets smashed), it's because the blow had a sideways (tangential) component, parallel to the surface. That tangential component produces shear stress, which makes the nail bend instead of sliding in cleanly.

Tensegrity minimizes shear stress by creating structures where the elements carry only normal loads, using precisely tensioned cables that force the pieces to hold each other in place. "We need to create a lightweight structure because we have to build something very large and precise, but affordable. And tensegrity seems one of the best ways to achieve that," Kuhn says.

Combining precision optics with a network of cables under tension demands a level of calculation and design without precedent. The team is using machine-learning tools to help with the structure's design. The network of cables and struts must also withstand environmental factors like wind, temperature changes, and seismic vibrations. Sensors and actuators will provide feedback, continuously adjusting tension to maintain the correct destructive interference to block the target star's light.

Given these extraordinary challenges, the team is starting with a scaled-down version. The Small ELF, or SELF, is already funded by the IAC for construction in late 2026 or early 2027 at the Izaña Observatory on Mount Teide in Tenerife. SELF will comprise fifteen 20-inch (0.5 m) mirrors, fabricated using curvature polishing, with a baseline of 11.5 feet (3.5 m). Although it will initially use a traditional rigid truss structure, SELF is designed so that a tensegrity system can eventually be mounted on it as an upgrade.

Part of SELF's role is to pave the way for ELF. "SELF could manage to observe a planet up to 10 million times fainter than its central star with the help of the machine-learning system we're developing," says Kuhn. One of SELF's goals is to directly detect the exoplanet Epsilon (ε) Eridani b, about 10.5 light-years away and expected to be near the limits of the telescope's capabilities. Of course, that planet is a gas giant with no visible surface features. But "with ELF, we hope to observe a planet a billion times less luminous than its star," says Kuhn.

Mapping other worlds

If ELF succeeds in directly imaging an Earth-like exoplanet — a feat never before accomplished — the planet will not occupy more than a single pixel. But that will enable astronomers to detect surface detail by observing the light that world reflects from its star. Breaking the light up by wavelength into a spectrum reveals the presence of features like oceans, ice, mountains, or deserts. Astronomers will need to watch as the planet rotates, spinning on its axis and moving along its orbit, producing periodic, repeating patterns in its spectrum as features move into and out of view. From those patterns astronomers can infer when certain features are visible and pinpoint their location — working backwards to reconstruct a map of the planet's surface.

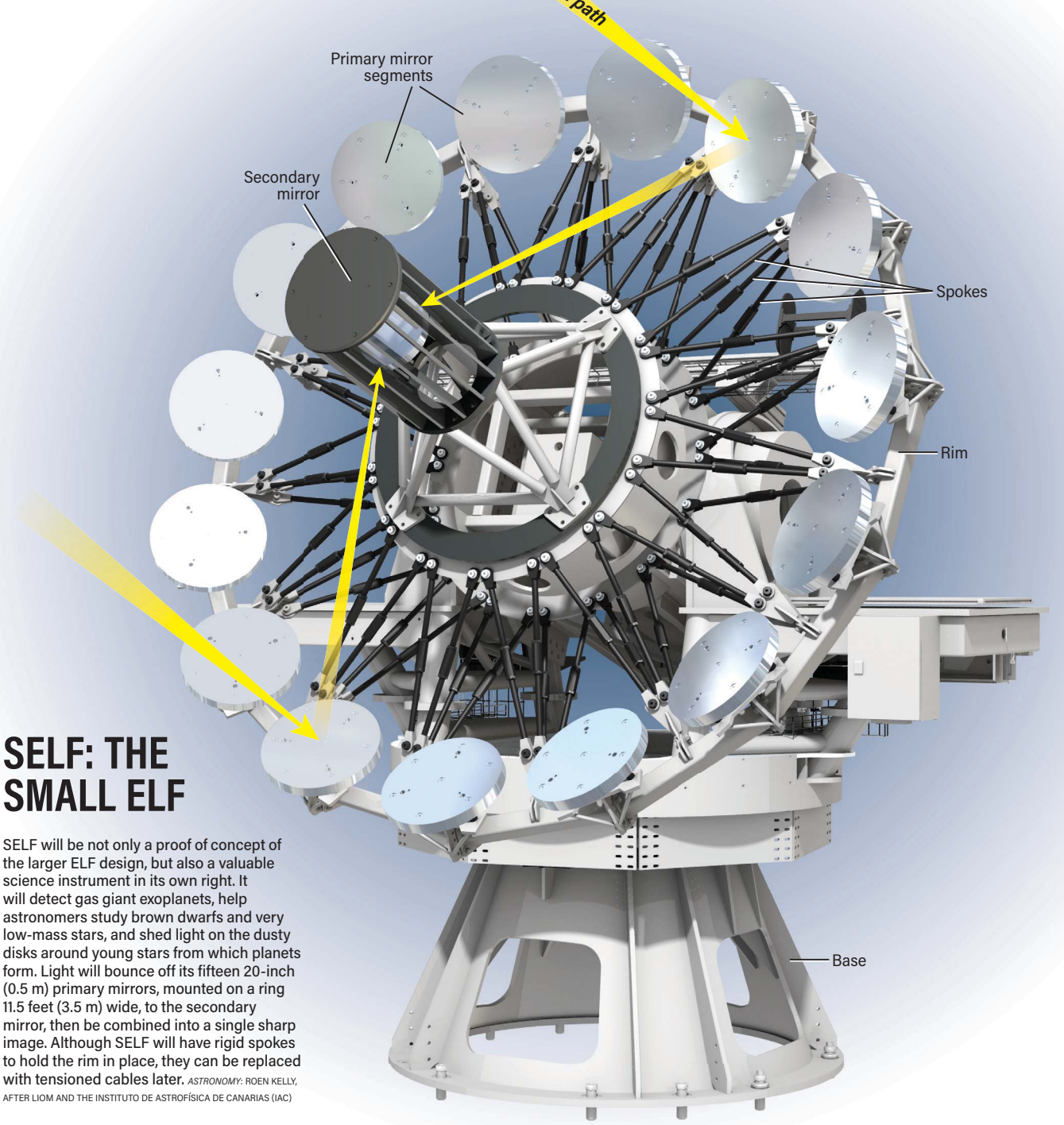
Called cartographic inversion, this technique requires a huge number of consecutive observations to disentangle signals from surface and atmospheric contributions and recover the chemical ingredients present on the planet. "If we have enough data points — a few hundred observations, or even a few thousand — then we can reconstruct a map of the planet, seeing where regions of higher reflectivity, or albedo, are and where regions of lower albedo or reflectivity are," says Max Dobat, an astrophysics graduate student at the University of Potsdam working on SELF.

"[W]e normally see planets simply as a blur," says Tarter. "The ExoLife Finder has these tricks that it

can play … so that when you look at the light that's reflected by the planet, you can tell whether it's beachfront, waterfront, or … desert. And that's getting us there. It won't show you the best locations to invest in terms of real estate, but it will show you the gross differences of planetary geography."

Notably, ELF will be able to accumulate data on the same targets night after night. Current methods to obtain spectra from small, temperate planets require us to watch as they pass in front of their star. This only works for planets that happen to be aligned by chance. And "if we are really looking for Earth-like planets" — orbiting at the same distance as Earth around a Sun-like star — "the transit occurs only once a year," says Dobat. ELF could be a game-changer, dramatically speeding up our ability to characterize exoplanets.

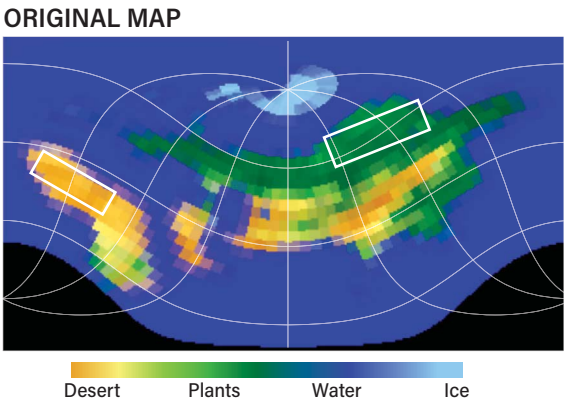
And what about finding life? Kuhn believes we could observe life by capturing the heat it produces, whether by biological or mechanical means. That's why ELF will also observe at infrared wavelengths of 1.0, 1.2, and 1.5 micrometers, where key molecular features and temperature contrasts between different regions on a planet become easier to detect. "The problem in detecting life is that there is no smoking gun, so to speak," he says. "It's a difficult question because we are conditioned by the life we see around us — the only kind we know. But it seems pretty clear to me that life is related to heat."

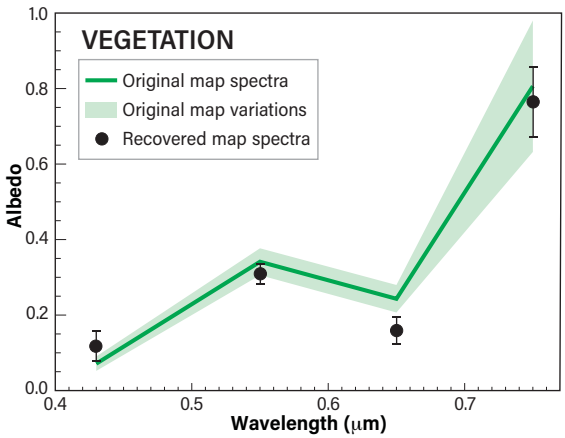


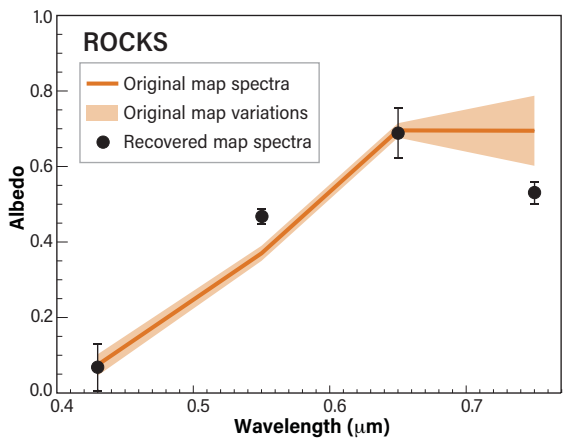
SELF: THE SMALL ELF

SELF will be not only a proof of concept of the larger ELF design, but also a valuable science instrument in its own right. It will detect gas giant exoplanets, help astronomers study brown dwarfs and very low-mass stars, and shed light on the dusty disks around young stars from which planets form. Light will bounce off its fifteen 20-inch (0.5 m) primary mirrors, mounted on a ring 11.5 feet (3.5 m) wide, to the secondary mirror, then be combined into a single sharp image. Although SELF will have rigid spokes to hold the rim in place, they can be replaced with tensioned cables later. *ASTRONOMY:* ROEN KELLY, AFTER LIOM AND THE INSTITUTO DE ASTROFÍSICA DE CANARIAS (IAC)

RECOVERING FEATURES







LEFT: To test ELF's ability to map exoplanet surface features, Kuhn and colleague Svetlana Berdyugina first generated an imagined exoplanet map (top), then modeled how well the cartographic inversion technique could recover the planet's features (lower map). This planet includes oceans (dark blue), a polar ice cap (light blue), and land covered by plants (green) and desert (yellow and orange). The charts at lower left show the amount of reflected light (or albedo), by wavelength, in the two areas outlined in white on each map. The top chart shows an area from the northern hemisphere of the planet covered with vegetation. The bottom chart shows a desert region from the planet's southern hemisphere. The solid lines show what a perfect spectrum of the "real" exoplanet would look like (the original map). The shaded regions show natural variations in albedo of the rectangular regions observed (i.e., the range of albedos within the boxed areas). The circles depict discrete datapoints from the recovered map, essentially mimicking observations of the planet with ELF — and show that ELF can pick up on differences in reflected light properties between vegetation and rock.

ASTRONOMY: ROEN KELLY, AFTER S. V. BERDYUGINA & J. R. KUHN, *THE ASTRONOMICAL JOURNAL* (2019), DOI 10.3847/1538-3881/AB2DF3 (CC BY 4.0)

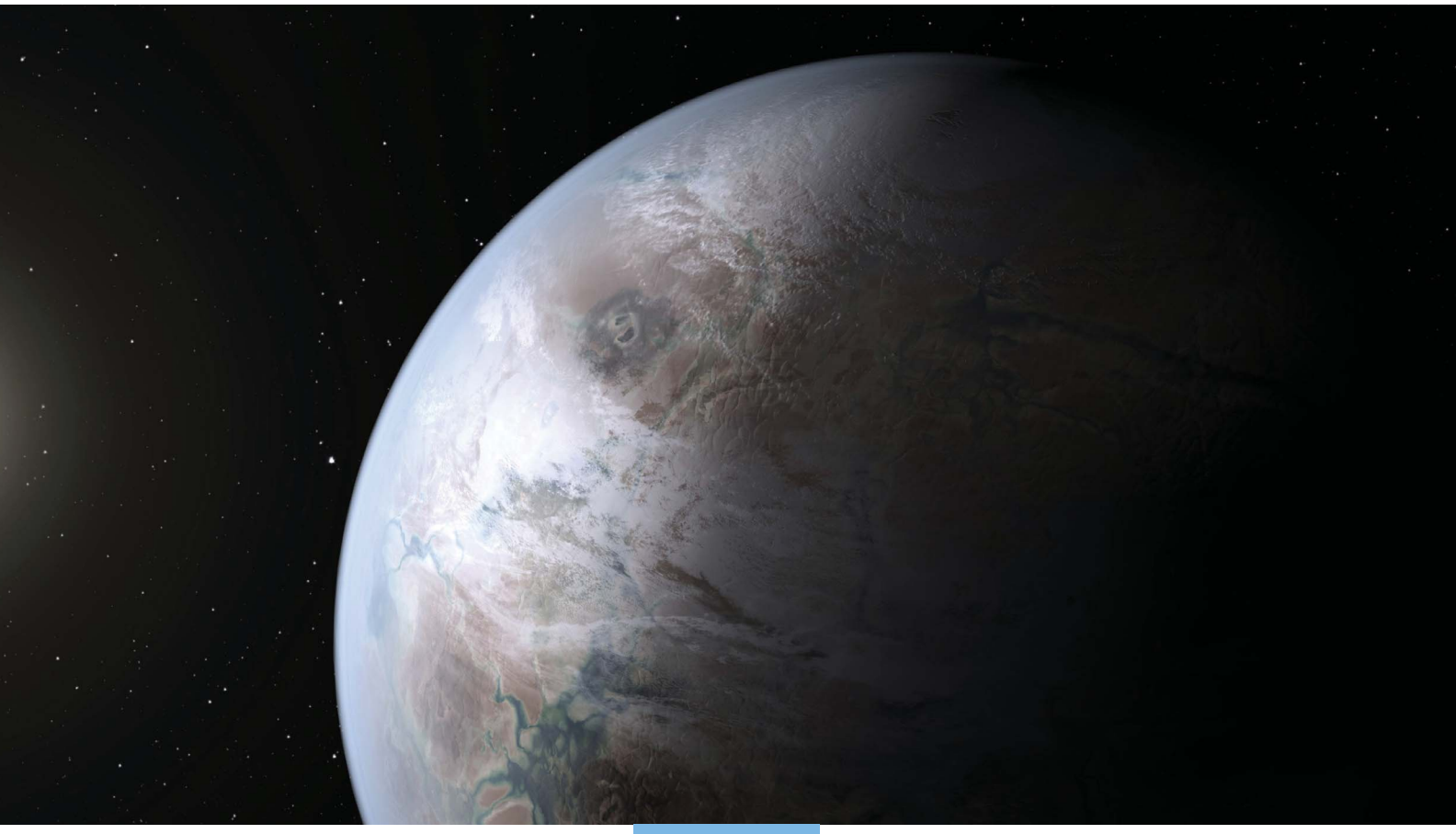
Kuhn and fellow University of Hawai'i scientist Svetlana Berdyugina have published several papers on the kind of thermal signal that large urban and industrial settlements would show on distant planets, an unmistakable sign of an intelligent civilization. For example, "If Los Angeles rotated in our field of view on an exoplanet, it would produce [an] almost-one-percent change in the infrared flux from population alone," Kuhn says. Transport, industry, power plants, home heating, and commercial buildings would all have a measurable impact as well. "Megacities, solar panels… all of that is detectable."

Toward the future

Kuhn hopes that when SELF sees first light around 2027, its proof of concept will attract support from investors and donors to build ELF. Still, it will be at least another decade before ELF might become operational. And given the technical challenges, its success is not a foregone conclusion, other astronomers say.

Mather is impressed by ELF, but notes that any disruptive science effort must deal with many unforeseen problems. "Simulations say it could be good enough," he says, but he's still not sure that it will reach the contrast needed to achieve its goals.

In the meantime, NASA has begun developing the Habitable Worlds Observatory (HWO) — the agency's next flagship observatory after the Nancy



This artist's concept shows the roughly Earth-sized Kepler-452 b (foreground) as a planet much like our own. Although this image is just a guess, ELF could soon let us map planets such as this to determine whether (and where) they have oceans, land, and even vegetation, turning artistic imaginings into reality. NASA AMES/JPL-CALTECH/T. PYLE

Grace Roman Space Telescope. HWO will rely on a traditional large mirror and internal coronagraph to image exoplanets. It is aiming for a launch in the 2040s. But given its cost — which Mather says is "unknown" but "presumably in the JWST category of many billions of dollars" — he is skeptical about NASA's ability to build it in the foreseeable future.

Another point in ELF's favor as a ground-based instrument is its size. HWO has to fit inside a rocket fairing for launch, and therefore "is much smaller in aperture than the ExoLife Finder and can't have nearly the angular resolution," says Mather.

This also limits how fast HWO can search for exoplanets, notes Ewan Douglas, an astronomer at the University of Arizona who builds exoplanet direct-imaging instruments. "Space observatories are always going to be smaller. … An instrument on the ground would have plenty of photons because now you're talking about 30-meter-class telescopes rather than 6-meter-class telescopes."

If ELF can identify Earth-like planets for follow-up, those would be of great value to future observatories with more exotic designs, he adds. For instance, some astronomers have proposed a spacecraft that could fly in formation, tens of thousands of miles away from a telescope like HWO, acting as a starshade to block the light of a host star. This combination would be more powerful than an internal coronagraph. But its ability to search for planets would be limited by the amount of time and fuel it takes to maneuver the starshade into position. "If we know where planets are, it's much easier to follow them up with space observatories," says Douglas.

Astrophysicist and science communicator Ethan Siegel believes ELF's technical challenges are surmountable and comparable to other innovative ground-based telescopes. "The biggest 'risk,'" he argues, "is that we could build it, acquire the spectrum of the many exoplanets-of-interest that we can image, and find nothing dynamical about any of them: just static, barren, cloudless, life-free worlds. But even that implies something profound."

Kuhn agrees: Whether or not ELF finds life, we will learn something about our place in the universe. A null result "would mean that life is rare, and we should treat it as such." It might also imply that "life probably did evolve elsewhere too, but then disappeared," he adds. "All these questions we're talking about bring the notion of life — and social questions about how life is organized — into a realm where astrophysics actually has something to say about it."

Thomas Villa *has published astronomy articles in* Focus *and* Coelum *magazines. He is based in Santa Cruz de Tenerife, Canary Islands, Spain.*

The young cluster Pismis 24 lies at the heart of the Lobster Nebula (NGC 6357) in Scorpius. The brilliant stars rank among the hottest and most massive in our galaxy. Tens of thousands of background stars add depth to this JWST infrared image. NASA, ESA, CSA, AND STSCI, A. PAGAN (STSCI)

FIRESTORM OF STARBIRTH

JWST reveals a massive young cluster at the core of the Lobster Nebula. BY RICHARD TALCOTT

IF YOU LOOK AT A PHOTO of a face-on spiral galaxy, you'll notice spiral arms filled with glowing gas clouds, sparkling star clusters, and opaque dust lanes curving gently away from the galaxy's core. An image of an edge-on spiral gives a completely different picture. The gas, dust, and stars now occupy a thin disk that shows just a hint of the gorgeous detail seen in their face-on cousins.

The same structures define the spiral galaxy we call home. The Milky Way may seem amorphous at first glance, but that's only because we see it from the inside. The big picture reveals that most of the young star clusters and the emission nebulae that give birth to them reside in a narrow strip that coincides with our galaxy's equator.

A cosmic crustacean

One of the finest examples of a newborn cluster emerging from its natal shroud lies less than 1° from the galactic equator in the constellation Scorpius the Scorpion. The Lobster Nebula (NGC 6357) spans nearly 300 light-years and holds enough raw material to produce tens of thousands of stars. Many of its first generation of stars reside in the massive open cluster Pismis 24 at the nebula's center.

The James Webb Space Telescope (JWST) recently captured this dazzling cluster in glorious detail. Astronomers targeted Pismis 24 because it lies only 5,500 light-years from Earth, a mere stone's throw away in galactic terms and thus a prime location for studying massive stars and the impact they have on their environment.

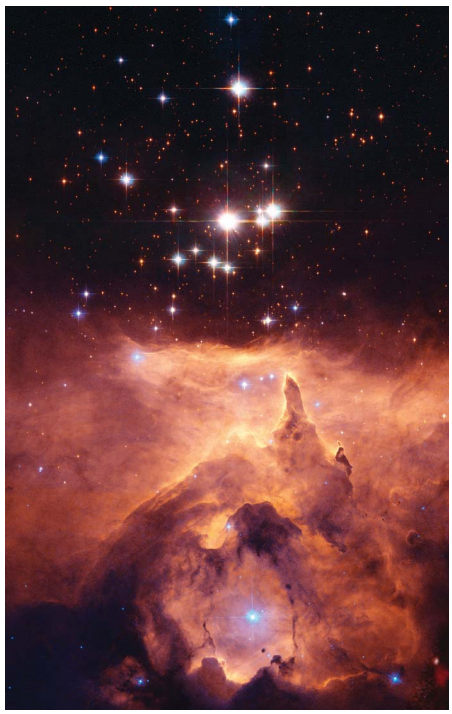
JWST's infrared eye penetrates much of the gas and dust that still envelops the cluster. The faint bluish haze that permeates the image shows hydrogen gas ionized by the hottest and most massive stars, while grains of dust glow with an orange hue and cooler, denser molecular hydrogen appears a deeper red.

Astronomers once thought the cluster's brightest star, Pismis 24–1 (seen at the image's center), might be the most massive star in our galaxy. Estimates of its heft ranged up to 300 solar masses, which would place it near the theoretical limit of what a star can weigh in today's universe. But more recent observations show it to be a binary system comprising stars of "only" 74 and 66 solar masses. At least a half-dozen other stars in Pismis 24 join these stellar heavyweights in spectral class O, the hottest class of normal stars.

The surface temperatures of these behemoths reach nearly eight times that of the Sun, so much of the radiation they pump out is energetic ultraviolet light. This ionizes hydrogen spread throughout the Lobster Nebula and causes it to glow with the characteristic reddish color seen in visible-light images.

A sculpting wind

These high-mass stars also generate fierce stellar winds, which clear out much of the surrounding gas and dust and create the cavity that allows us to see Pismis 24. The densest regions of gas and dust can resist the onslaught for a time, creating colorful spires reminiscent of the famous "Pillars of Creation" seen in the Eagle Nebula.



Hubble combined visible and infrared images to create this 2006 portrait of Pismis 24. Because Hubble's vision does not penetrate dust as well as JWST, the number of stars visible falls dramatically.
NASA, ESA, AND JESÚS MAÍZ APELLÁNIZ (INSTITUTO DE ASTROFÍSICA DE ANDALUCÍA, SPAIN)

The tallest tower appears slightly below center and points upward directly toward Pismis 24–1. The spire's tip measures 0.14 light-year across, which means more than 100 solar systems (out to the orbit of Neptune) could span its width. But don't expect lots of planetary systems to develop in this region. Astronomers estimate the frequency of protoplanetary disks near Pismis 24 to be lower than in similar clusters, perhaps due to its exceptionally strong wind and radiation environment.

Contributing Editor **Richard Talcott** *wrote about JWST's observations of the young star IRAS 04302+2247 in the March issue.*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.
BY MARTIN RATCLIFFE AND ALISTER LING

Brilliant Venus hangs beneath the Pleiades at right in this April 2015 image, reminiscent of the evening sky early this month. ALAN DYER

APRIL 2026

Venus shines at dusk

Exciting planetary action takes place this month. Venus and Uranus vie for attention and lie close to each other in late April. Jupiter offers a lot to observe through a telescope, particularly events involving its Galilean moons. The rest of the action takes place just before dawn, with Mars, Mercury, and Saturn making an appearance in late April. And remember to take time out to watch the Lyrid meteor shower, with no Moon to interfere.

Venus is brilliant in the western sky soon after sunset. On April 1 it stands 13° high 30 minutes after sunset and shines at magnitude –3.9. Twenty minutes later, as twilight darkens, the stars of Taurus the Bull and the Pleiades star cluster (M45) pop into view above it.

During the month, Venus slides from Aries into Taurus. Venus moves into Taurus on April 18, just as the crescent Moon climbs up to sit adjacent to the planet in the evening sky. They stand 6° apart, with M45 7° above Venus in a stunning evening display.

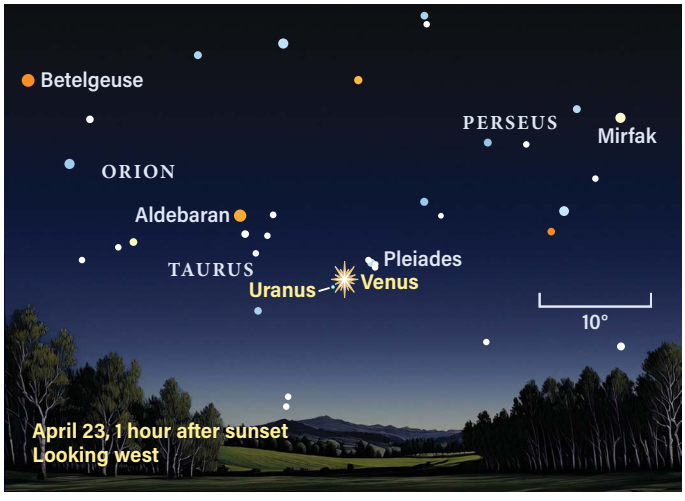
The Moon, just over 1½ days old, displays beautiful earthshine, so the entire globe of our satellite is visible against the darkening sky. Watch until it sets soon before 10 P.M. local daylight time. The following evening, April 19, the Moon stands 5° east of M45.

A special conjunction occurs April 23, when Venus stands 45' north of **Uranus**. The Pleiades are about 3.5° north of Venus. Uranus can be spotted with binoculars — just point at Venus and look for the faint, flat "star" to its south, shining at magnitude 5.8. That's the seventh planet from the Sun. One day on either side of conjunction, Uranus stands within 1.5° of Venus, still a great time to spot the distant planet.

Venus moves deeper into Taurus, ending the month near a pair of 4th-magnitude stars, Kappa (κ) and Upsilon (υ) Tauri. Use a telescope the evening of April 30 to capture the view of Venus with these bright stars, along with 5th- and 6th-magnitude field stars nearby.

Venus' telescopic appearance changes throughout April. On the 1st, it spans 11" and displays

Close encounter



Uranus stands less than 1° south (to the lower left) of bright Venus April 23. You will need binoculars or a telescope to spot the distant ice giant. Higher in the west will be Jupiter and a waxing Moon. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

VENUS and **URANUS** appear just 45' apart on the evening of April 23.

a 94-percent-lit disk. At the end of the month, Venus has grown to 12" wide and is 88 percent lit.

Returning to Uranus, on April 1 you'll find the dim planet near a pair of stars 4.5° south-southwest of M45. Binoculars will easily find 13 and 14 Tau, shining at magnitude 5.7 and 6.1, respectively. Uranus is 16' east of 14 Tau on April 1. By April 16, Uranus has moved to stand 1° east of this star. It extends the gap to 1.7° by April 30. As usual this year, use the Pleiades as your main guide to finding Uranus. A telescope will reveal a disk spanning 3" with a subtle bluish-green hue.

Jupiter shines brilliantly, high in the western sky after sunset. It is a beautiful magnitude –2.1 addition to Gemini the Twins. It dims by just 0.1 magnitude by the end of April. The gas giant is visible all evening, setting around 3 A.M. local daylight time on the 1st, and by 1:15 A.M. on the 30th.

Jupiter moves eastward against the backdrop of Gemini. It's joined by a waxing crescent Moon on the 22nd, with the 4th-magnitude star Wasat (Delta [δ] Geminorum) roughly 1° southeast of Jupiter. By April 29, Jupiter stands just 0.5° (a Full Moon's width) due north of this star.

Jupiter's attraction, aside from its brilliance, is the wealth of detail visible through any telescope.

— *Continued on page 34*

RISING MOON | A fortnight of features

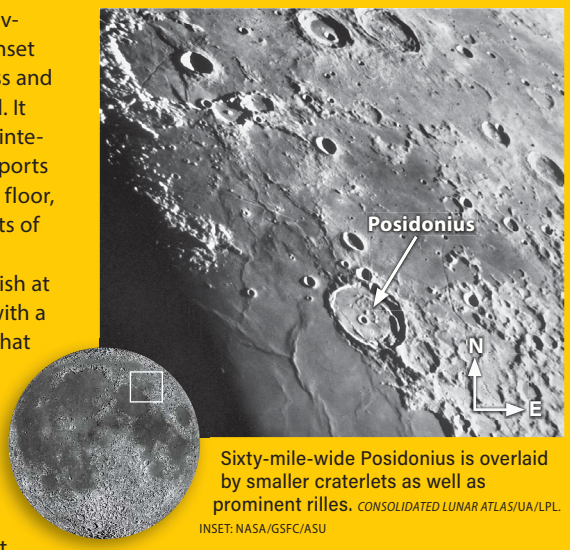
PACKED WITH DETAIL, the large crater Posidonius is near the top of the lunar lover's list. Catch a sneak peek as you finish observing on the night of the 6th, when lunar sunset lengthens the shadows as the minutes pass and features become increasingly exaggerated. It returns to light on April 22. The lava-filled interior of this 60-mile-wide, age-old impact sports cracks, jumbled peaks poking up from the floor, an off-center craterlet, and bright segments of slumped walls.

Unlike most craters that seemingly vanish at Full Moon, Posidonius brags a bright rim with a cream-pie face full of detail on the inside that lasts into May. Long shadows that were obvious last week have disappeared under a high Sun. Instead, the variety of gray we see comes from the differences in albedo, or reflectivity. The darker lava on the flooded floor contrasts nicely against the brighter specks of small impact events and the curved light of a slumped terrace, whose face aims upward.

Look for Posidonius in the northeastern quadrant of the Moon. Posidonius B is a noticeable 9-mile-wide fresh impact on the northeast rim, while the slightly smaller crater A has the sharp edges of youth. Age is relative, since a "fresh" feature here is 100 million years old.

Easily confused with Poseidon, the Greek god of the sea, Posidonius is actually named after a Greek astronomer and philosopher who lived around 100 B.C.E.

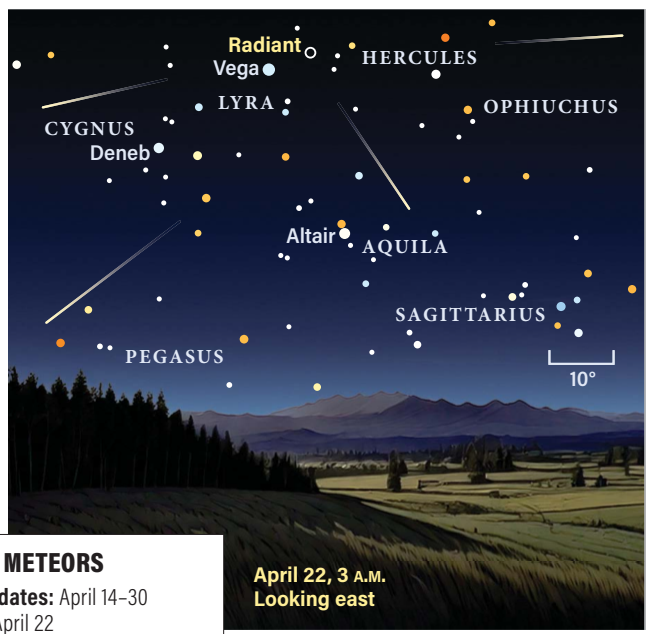
Posidonius



Sixty-mile-wide Posidonius is overlaid by smaller craterlets as well as prominent rilles. *CONSOLIDATED LUNAR ATLAS/UA/LPL.* INSET: NASA/GSFC/ASU

METEOR WATCH | Clear viewing

Lyrid meteor shower



The Lyrids' radiant is high in the east in the hours before dawn. Use this chart to locate it on the 22nd or 23rd, when meteor rates will be highest.

LYRID METEORS

Active dates: April 14–30
Peak: April 22
Moon at peak: Waxing crescent
Maximum rate at peak: 18 meteors/hour

THE LYRID METEOR SHOWER is active from April 14 to 30, peaking the night of April 22. The radiant, located near Lyra, rises in the late evening and reaches an altitude of about 20° at local midnight. Once the few-day-old Moon sets, shortly after 1 A.M. local daylight time on the morning of the 22nd and an hour later on the 23rd, dark skies continue through to dawn. Lyra approaches the zenith just before dawn, offering the best viewing in a dark sky. Meteors tend to be more abundant in the predawn hours, as the shower particles strike Earth's atmosphere at a higher relative velocity.

The Lyrids typically produce a zenithal hourly rate of about 20 meteors per hour. With Lyra positioned high above the horizon after 2 A.M., the early-morning sky offers one of the best opportunities to view this seasonal meteor shower.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

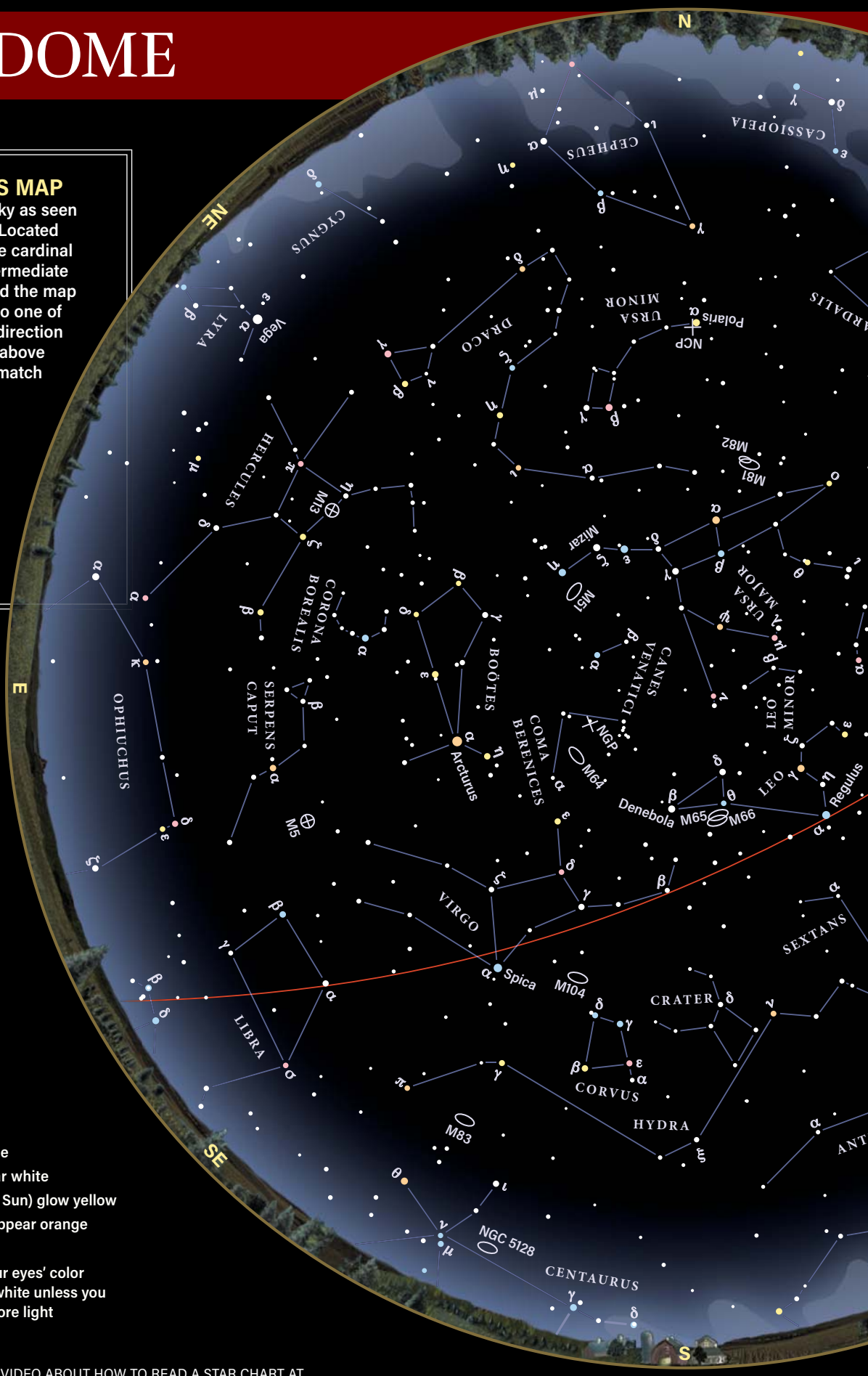
STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

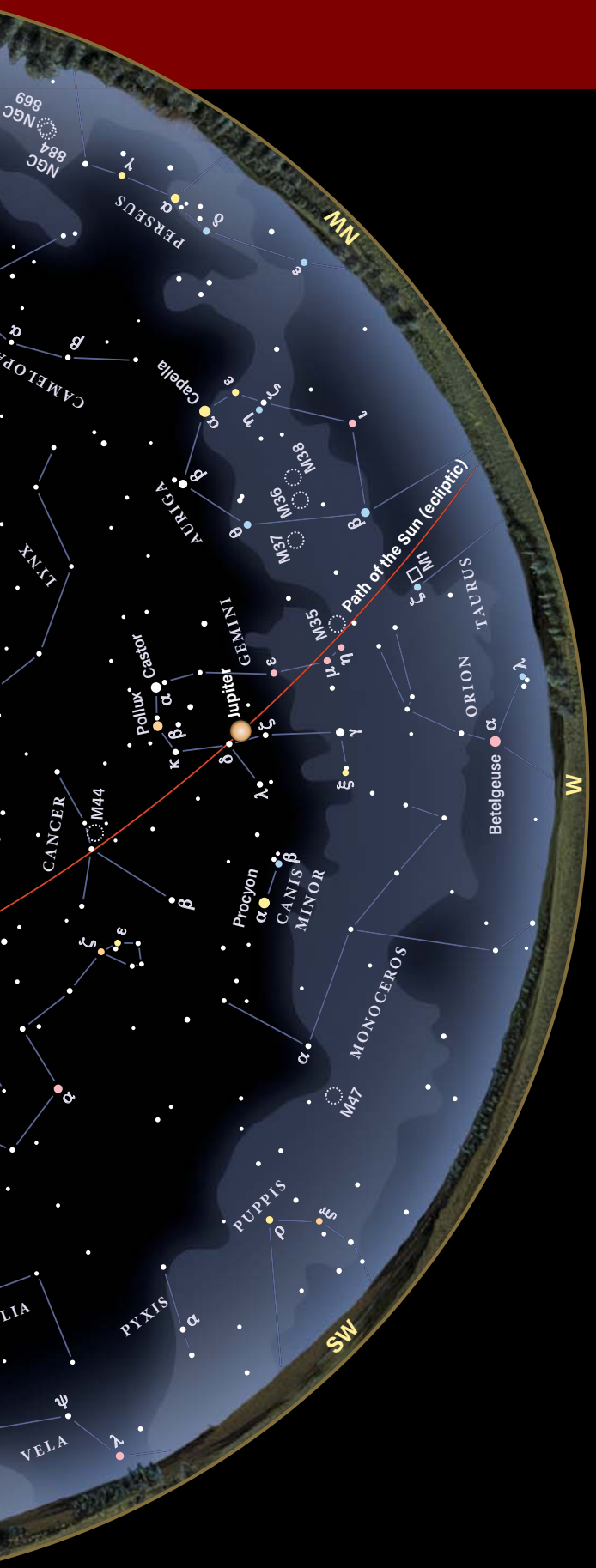
STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



APRIL 2026

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Full Moon occurs at 10:12 P.M. EDT

3 Mercury is at greatest western elongation (28°), 7 P.M. EDT

6 The Moon passes 0.6° south of Antares, 4 P.M. EDT

7 The Moon is at apogee (251,637 miles from Earth), 4:31 A.M. EDT

10 Last Quarter Moon occurs at 12:52 A.M. EDT

13 Mars passes 0.3° north of Neptune, 6 A.M. EDT

15 The Moon passes 5° north of Mercury, 3 P.M. EDT

The Moon passes 4° north of Neptune, 5 P.M. EDT

The Moon passes 4° north of Mars, 9 P.M. EDT

16 The Moon passes 5° north of Saturn, 2 A.M. EDT

Mercury passes 1.4° south of Neptune, noon EDT

17 New Moon occurs at 7:52 A.M. EDT

19 The Moon is at perigee (224,707 miles from Earth), 2:56 A.M. EDT

The Moon passes 5° north of Venus, 5 A.M. EDT

The Moon passes 5° north of Uranus, 2 P.M. EDT

Mercury passes 1.8° south of Mars, 8 P.M. EDT

20 Mercury passes 0.5° south of Saturn, 4 A.M. EDT

Mars passes 1.3° north of Saturn, 2 P.M. EDT

22 Lyrid meteor shower peaks

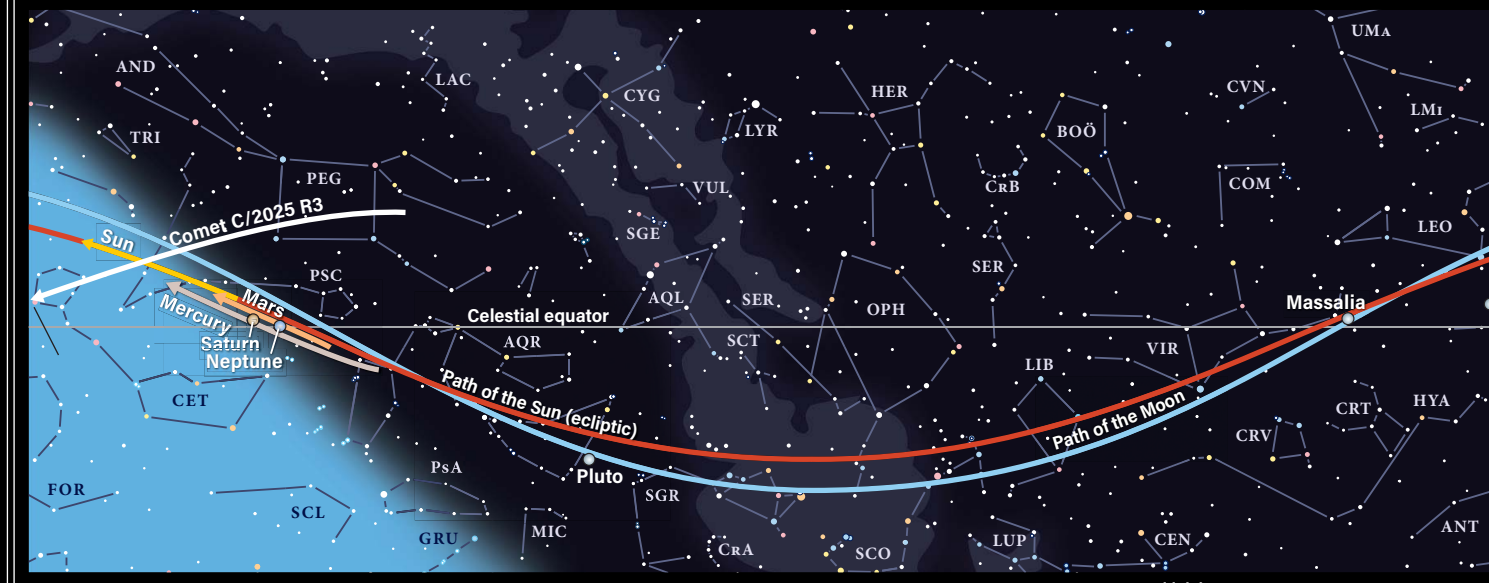
The Moon passes 4° north of Jupiter, 6 P.M. EDT

23 First Quarter Moon occurs at 10:32 P.M. EDT

24 Venus passes 0.8° north of Uranus, 1 A.M. EDT

25 The Moon passes 0.2° north of Regulus, 9 P.M. EDT

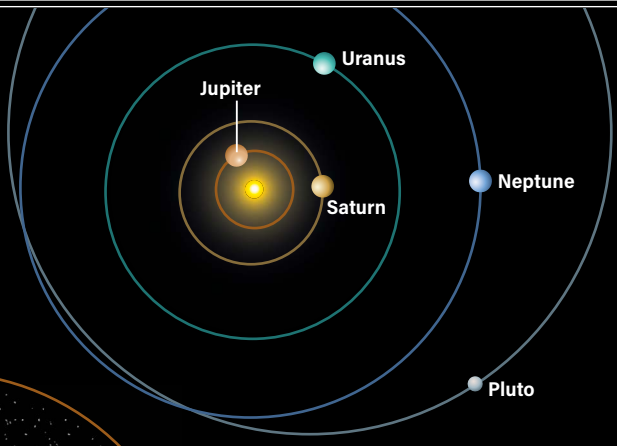
PATHS OF THE PLANETS

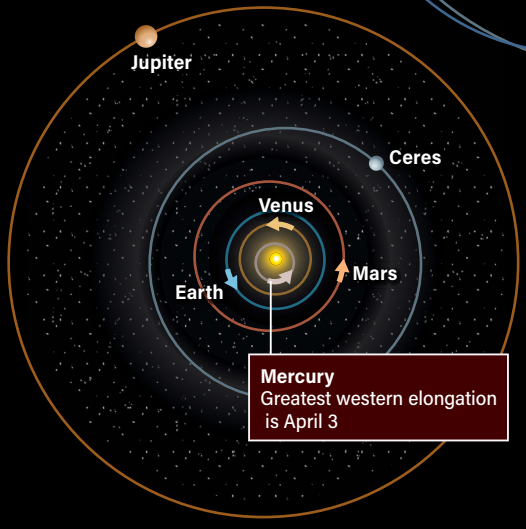


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

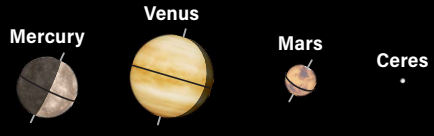
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

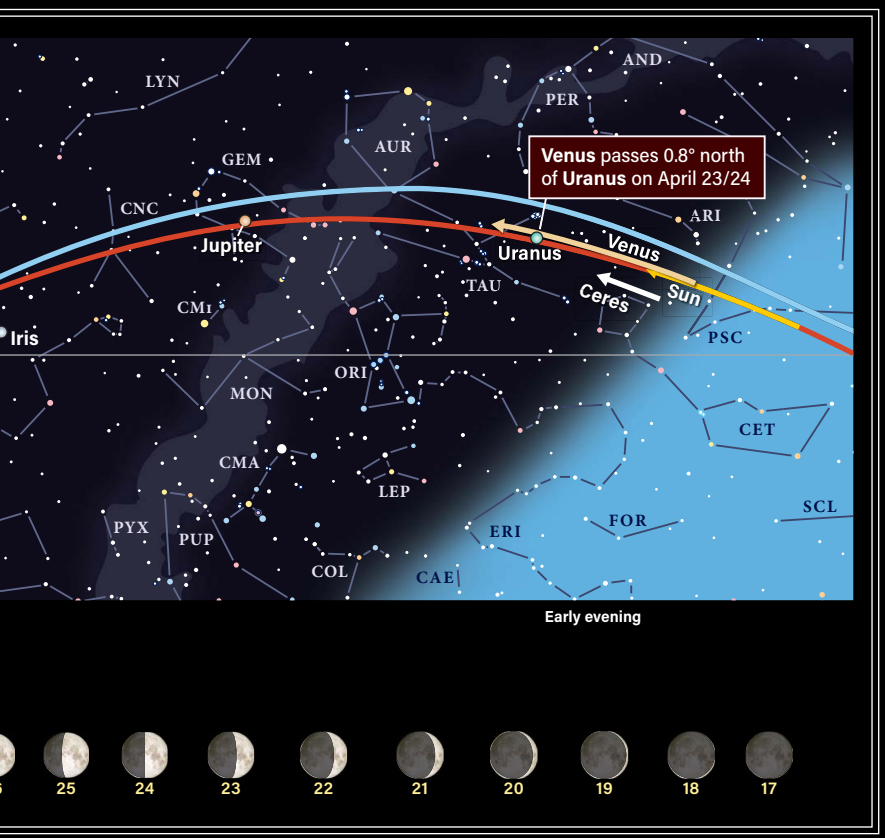
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	April 1	April 15
Magnitude	0.4	–3.9
Angular size	8.0"	11.0"
Illumination	45%	91%
Distance (AU) from Earth	0.842	1.514
Distance (AU) from Sun	0.465	0.720
Right ascension (2000.0)	23h00.6m	3h03.8m
Declination (2000.0)	–7°45'	17°29'

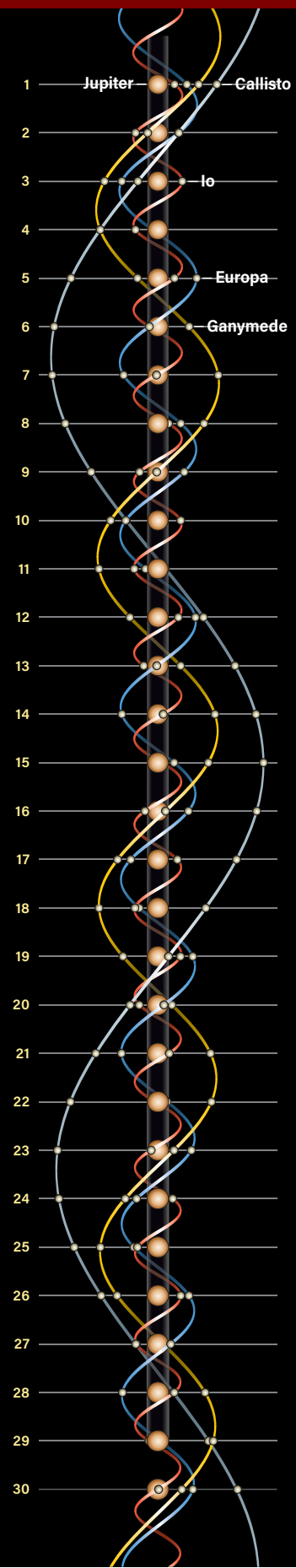
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

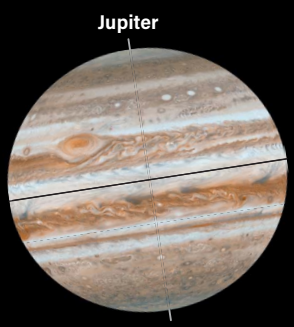
APRIL 2026

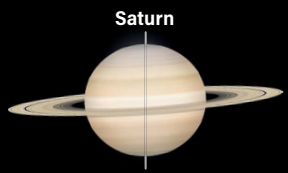


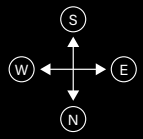
JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.









10"

Uranus Neptune Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
April 15	April 15	April 15	April 30	April 15	April 15	April 15
1.2	8.9	–2.1	0.9	5.8	7.8	15.3
4.1"	0.4"	37.2"	16.1"	3.5"	2.2"	0.1"
98%	100%	99%	100%	100%	100%	100%
2.273	3.751	5.295	10.334	20.291	30.808	35.659
1.384	2.811	5.249	9.482	19.472	29.882	35.493
0h15.0m	2h42.4m	7h12.2m	0h35.3m	3h47.5m	0h10.7m	20h33.7m
0°33'	11°15'	22°47'	1°27'	19°47'	–0°16'	–22°53'

 — Continued from page 29

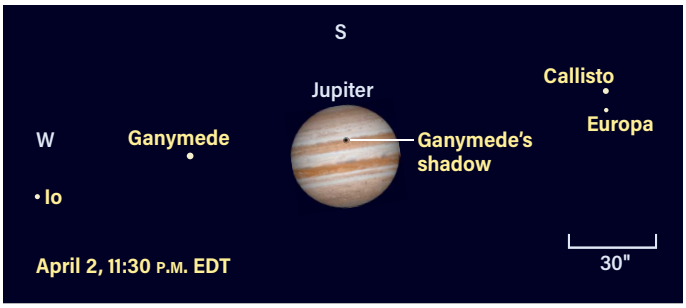
WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (west)
Jupiter (west)
Uranus (west)

MIDNIGHT
Jupiter (west)

MORNING SKY
Mercury (east)
Mars (east)
Saturn (east)
Neptune (east)

The full set



Late on April 2, catch all four Galilean moons as Europa passes north of Callisto and Ganymede casts its shadow on Jupiter.

Primarily — and most noticeable at first — are the two dark equatorial belts. More subtle features on other parts of the globe, which spans a healthy 39" in early April, come into view during moments of steady seeing, provided you are a patient observer. Earth is speeding around its orbit and increasing our distance from Jupiter, so the disk shrinks to 36" by April 30.

Most observers want to see the Great Red Spot as it's carried around the planet on its 9-hour 55-minute rotation period. The large oval storm sits on the edge of the South Equatorial Belt and is typically visible every other night.

Check out Jupiter early on the evening of April 1 (before midnight EDT) because the Galilean moons are all visible east of the planet in order of distance. Closest to Jupiter is Io, followed by Europa, Ganymede, and finally Callisto. Continue observing through the evening because over a couple of hours you'll see Io and Europa moving farther east, until Europa swaps position with Ganymede at 2:20 A.M. EDT (now April 2 for much of the U.S.), when the former passes 7" due north of the latter. You're seeing orbital dynamics in motion!

The shadows of both Ganymede and Callisto cross Jupiter's face on consecutive nights, April 2 and 3. Around 11:30 P.M. EDT on the 2nd, Europa stands 7" north of Callisto, while the shadow of Ganymede is midway across Jupiter. Ganymede itself is west of the planet, showing the angle of the Sun. The eastern half of the U.S. will see the shadow transit begin around 9:58 P.M. EDT. The transit ends at 1:22 A.M. EDT (the 3rd for the eastern half of the U.S.), better viewed from the western half of the country.

Callisto's shadow transits April 3 with similar timing. The shadow first appears at 9:14 P.M. EDT and takes over four hours to cross the planet, longer than Ganymede's because Callisto lies farther from Jupiter and consequently its shadow moves more slowly across the planet. The transit ends at 1:32 A.M. EDT (now the 4th in the Eastern and Central time zones). Because the shadows of both Ganymede and Callisto are so large, watch for the start of the transits a few minutes before the predicted time and see when you first notice the black notch appear. The shadow's first appearance is heavily affected by your local seeing conditions.

On the 4th, Europa slips behind Jupiter's disk at 11:30 P.M. EDT and remains hidden for nearly three hours, but isn't visible when it clears the limb because it lies deep inside the planet's extended shadow. It finally reappears one jovian disk diameter east of the planet's eastern limb more than five hours later, only visible from the western half of the

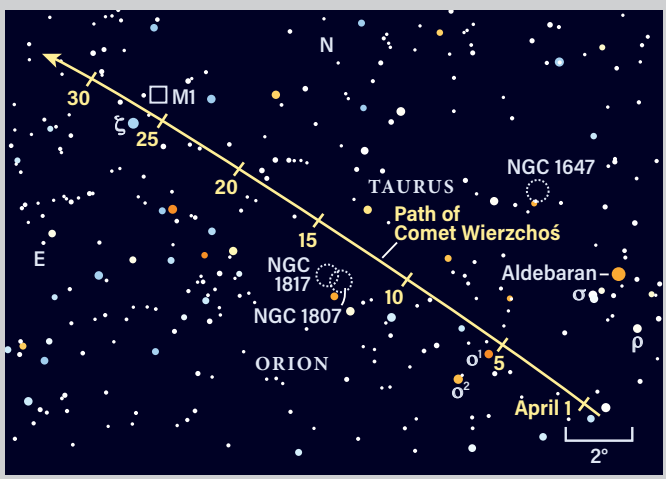
COMET SEARCH | One after another

AS THE MOONLESS evenings begin April 4, get to a dark site to say farewell to 10th-magnitude C/2024 E1 (Wierzchoś), modestly high in the west as it slides past Aldebaran. When the lunar crescent returns in mid-April, the comet's retreat has eaten another magnitude off its shine. An 8-inch scope at medium power reveals a form similar to a lopsided galaxy. Ardent imagers can capture a moonlit pairing with M1 (the Crab Nebula) on the 27th as the coma's pale green glow dies out.

Let's reintroduce Comet 10P/Tempel, also known as Tempel 2, which is on the way in for an extended stay over the summer. Already brightening past 9th magnitude, its dark-sky window opens overnight April 11/12 as you're closing up at 3 A.M. During the New Moon Messier marathon, the nearly round fuzz is crossing the Scutum Star Cloud, near doppelgänger globular NGC 6712.

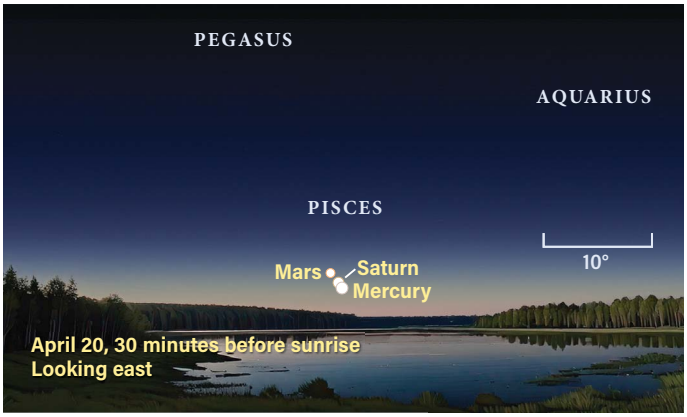
Don't dally with C/2025 R3 (PanSTARRS). It hits binocular range crossing the Square of Pegasus mid-month, disappears into the dawn a week later, then fades rapidly in a Southern Hemisphere moonlit evening sky shortly after.

Comet C/2024 E1 (Wierzchoś)



Comet Wierzchoś is fading on its way through Taurus, though it still offers a nice photo op with M1 late in the month. For details on the path of Comet Tempel 2 this month, visit our website.

Predawn trio



Shortly before sunrise on April 20 is a great opportunity to spot three planets together. You will need a clear eastern horizon and binoculars to catch them all.

U.S., around 2 A.M. PDT on April 5, with Jupiter sinking very low in the western sky.

Ganymede's shadow begins another transit April 10 at 12:57 A.M. CDT (late on the 9th farther west), visible from the western two-thirds of the U.S. Jupiter sets while the shadow transit is underway.

Eagle-eyed observers may spot Callisto reappearing at Jupiter's northeastern limb April 11 at 8:27 P.M. EDT. This moon is far enough from Jupiter to avoid the planet's shadow.

Io and Europa undergo regular, frequent events. We don't list them all, but an interesting one occurs April 13/14. Europa is transiting the planet as darkness falls on April 13 across the Central and Mountain time zones. Shortly before the transit ends at the western limb, Europa's shadow appears at the eastern limb at 11:42 P.M. EDT. Europa leaves the disk 18 minutes later.

Watch as Europa continues westward, while Io (already to Jupiter's west) moves eastward. Io stands 5" north of Europa soon after midnight CDT. Their relative motion can be spotted within a few minutes.

The following night, Io has come around the back of Jupiter and transits along with its shadow, beginning at 11:25 P.M. EDT on the 14th.

Ganymede transits Jupiter south of the South Equatorial Belt April 16/17 beginning at 12:53 A.M. EDT (the 17th in the Eastern time zone only, late on the 16th farther west). The large moon takes over three hours to cross the disk. Observers in the Pacific time zone will see the transit end.

The last event of note is the reappearance of Ganymede far from Jupiter's eastern limb on April 28. It comes out of eclipse at 12:19 A.M. PDT, east of the limb by some 1.3 times Jupiter's apparent diameter. The moon slowly brightens over a couple of minutes. It's challenging to watch from the Mountain time zone due to the planet's low altitude, but Pacific Coast observers should have a ringside seat.

Mars, **Mercury**, and **Saturn** lie within 2° of each other on April 20. Located in the morning sky soon before sunrise, spotting them will be difficult. They stand about 2° high due east 30 minutes before sunrise. Your best chance is to spot the brightest of the trio, Mercury, shining at magnitude –0.2. Next brightest is Saturn, standing 28' north of Mercury and shining at magnitude 0.9. It will likely need binoculars or a low-power telescope to view. Mars stands 1.2° north of Saturn, and is the dimmest at magnitude 1.2.

Viewing dim planets at low altitude is difficult due to haze. You can overcome this if you have access to mountains: Higher altitude reduces the effects of atmospheric scattering and renders dimmer planets easier to spot.

Saturn becomes a bit easier to view by April 30, standing 3.5° high in the east 45 minutes before sunrise on this morning.

Neptune, in the same region as Mars and Saturn, is only 4° high in the east an hour before sunrise on the 30th. It is too faint to be readily visible.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

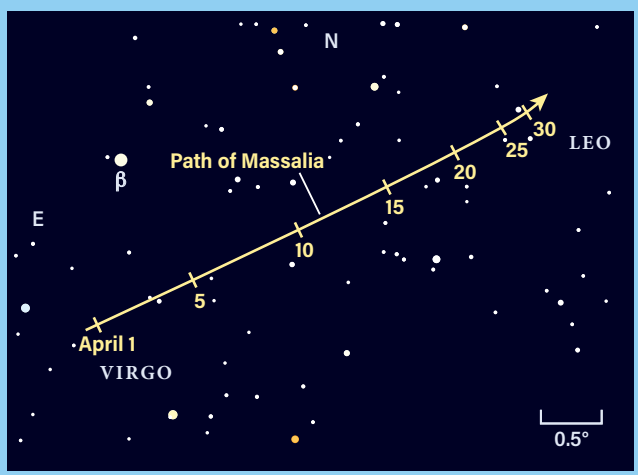
LOCATING ASTEROIDS
I see you

ORBITING AT A SAFE viewing distance in the main belt is 20 Massalia, within reach of a 3-inch scope from the suburbs. Climbing up the southeastern sky, it's a 2° to 3° hop from Beta (β) Virginis, about halfway between the luminaries Spica and Regulus.

It shouldn't be tough tracking down the 90-mile-wide Massalia in this star-poor region far from the Milky Way. Our target's modest, magnitude 9.7 glow outshines many of the background stars here. A direct go-to might show you a single dot in the field, in which case it's a good idea to slightly shift the scope north or south to encounter the stars on our chart for reference. From Naples, Italian astronomer Annibale de Gasparis visually compared his fields of view with star charts to discover Massalia in 1852. He bagged nine asteroids in all with this method.

From April 3–4 and 16–20, there are nearby field stars to use as a reference for noting Massalia's displacement from one night to the next.

Visiting Virgo



Massalia is moving through Virgo this month, easy to find near magnitude 3.6 Beta Virginis.

ANDY WEIR on *Project Hail Mary*

WHAT WOULD YOU DO if you woke up on a spaceship light-years from Earth without knowing why you're there?

Based on the *New York Times* bestselling novel by Andy Weir, who also penned *The Martian*, Amazon MGM Studios' *Project Hail Mary* follows science teacher Ryland Grace (Ryan Gosling) as he slowly recalls his mission: to solve the problem of Astrophage, an extraterrestrial life-form consuming the Sun's energy and sending Earth hurtling toward an ice age. He's on his way to Tau Ceti, the only nearby star *not* dimming, to discover why it seems immune. But he won't have to uncover the answer alone — along the way he meets Rocky, an alien whose sun, 40 Eridani, is suffering from Astrophage as well.

Project Hail Mary opens in theaters March 20. Ahead of the film's release, *Astronomy* spoke with Weir about several aspects of the project, from his inspiration for the story to the process of bringing a book to the big screen.

The following interview has been edited for length and clarity. It also contains spoilers for the film.

***Astronomy*: Could you talk about your inspiration for the story?**

Weir: It's actually several different ideas that I've had over the years that I kind of glued together and sanded off the seams. I have, for a long time, wanted a story about first contact. I had this random idea for a story about a guy who wakes up aboard a spaceship with amnesia. And then also, the idea of a mass-conversion-based fuel [a fuel that operates by converting matter into energy].

The mass-conversion-based fuel thing I had included in an abandoned book I was working on called *Zhek*. *Zhek* didn't work, but what if we had that mass-conversion fuel today? We could colonize the solar system — not in some far-flung future, but right now. But how do I explain how we, today, have it? I can't have a mad scientist invent it. It's so far beyond our technology. Maybe they could find it in an old, crashed alien spaceship or something. That would be cool, but then you can't build an infrastructure on it, there's just the fuel on the ship.

← *Project Hail Mary* is author Andy Weir's second novel to become a feature film, after *The Martian*.
AUBRIE PICK

Mary

The bestselling author discusses his inspiration, creative process, and favorite scientific tidbits behind the feature film. BY ALISON KLESMAN

Project Hail Mary stars Ryan Gosling as Ryland Grace, who finds himself light-years from home on a mission to save our dying Sun. JONATHAN OLLEY/COURTESY AMAZON MGM STUDIOS

Instead, what if this is a thing that absorbs energy and makes more of itself? That sounds like a life-form. So what if it's a life-form that can do mass conversion? Well, it would have to live on the surface of stars. And what if it spores out like a mold to get to other stars? That would also explain why it has to do all this mass-conversion stuff, because it needs a lot of energy to go to other stars.

And let's say that we get ahold of some of this. It's an extraterrestrial life-form, but it's just a microbe, so you're not asking where that civilization is. And then I'm like, oh, we'd have to be really careful to make sure that s--- didn't get onto our Sun. And then I'm like, one Mississippi, two Mississippi… Oh, wait, no, that's the story. This is how we discovered it, it's already infected our Sun.

Well, then, what do you do about it? Well, it has to have a homeworld. Wherever it has a homeworld, it probably has a predator. So that would be the one star in the area that isn't dimming, so they'd probably see that. Then they'd have to make a ship and go there, and they have their mass-conversion fuel so they can. And then oh, that means I can put my amnesia guy in there. And then, hey, I could do first contact! I could have an alien whose species has the same problem. So each

thing kind of led to the next. It really worked out very nicely.

***Astronomy*: Do you come up with problems and then do research to solve them, or does researching present problems and solutions at the same time?**

Weir: The latter is what happens most often. A good example is the sequence in *The Martian* where Watney has to make water for his potatoes. It didn't even occur to me, except I was researching "How do you make potatoes?" And the moisture content of the soil has to be at least such and such. I did the math and for his farm, he'd need something like 600 liters [about 159 gallons] of water, and there's just no way they would have brought that much for a Mars mission for six people. So I have to explain where he gets the water, and then that whole plotline came along because of that.

In general I don't think up a whole bunch of problems. What I like to do is just set things in motion and then see where they lead. *The Martian* is all one big cascade failure. *Project Hail Mary* is actually a fairly linear plotline once all the twists are revealed.

***Astronomy*: Of course in science fiction, we expect fiction. But how realistic does the science need to be for you to be happy with it?**

Weir: As a writer, I want to find the absolute minimum way that I can break the rules and then just do that. In *Project Hail Mary*, you have to go all the way down to the quantum realm, where the cell membrane of Astrophage has super cross-sectionality, which means neutrinos have a zero percent chance of tunneling through.

Neutrinos routinely just pass clean through the entire planet Earth without colliding with a single atom, right? But for some reason, the cell membrane of Astrophage — which is where it's turning heat energy into neutrino mass — is also somehow super cross-sectional. Those two things are linked. So, both the method by which it makes neutrinos and the fact that it is super cross-sectional, that's my little quantum level of bulls--- that everything else is based on. *[Editor's note: Astrophage convert heat into neutrinos, which they store and later annihilate to create energy to propel themselves through space to other stars.]*

Later on I realized Astrophage would be a perfect radiation shield. Nothing quantum tunnels through it. It doesn't matter if it's gamma rays or protons going 0.9999999*c* [*c* = the speed of light]. It might kill the Astrophage, that cell, it's so much energy dumped into it, but it's not gonna get through. It's a handy thing. *[Editor's note: Astrophage is used to line spacecraft walls to protect the astronauts within.]*

I think one of the most fun things was I worked out the maximum velocity the *Hail Mary* would have during its trip, and it's very close to *c*, right? At that velocity, the interstellar medium would have a drag effect on the ship. Out in between two stars, there's like one hydrogen atom per cubic meter. But when you're going that fast, you encounter so many of them that I made the ship actually streamlined. It had to have some aerodynamics to it for the interstellar flight. And that's kind of cool. Your spaceship has to be a little bit aerodynamic to deal with the drag.

***Astronomy*: How much input did you get on the movie?**

Weir: On *The Martian*, my only job was to cash the check. They chose to involve me, which I was grateful for, but mostly it was just technical questions.

Things are very different on *PHM*. I'm a producer on the film, so I was involved at every step of the way. I was there for almost the entire shoot, and the directors and the other producers included me on everything. I was used very heavily as a science advisor.

***Astronomy*: Were there any scenes that you expected to be hard to film that weren't, or vice versa?**

Weir: We all knew that the zero-g scenes were gonna be hard, and we were right. It's very difficult to be in the wire harness and made to float around, and it's very physically demanding and physically uncomfortable. And we didn't use a double; for the most part it's Ryan hanging from wires all day. It was not comfortable. He's a professional, though.

↓ Grace is a science teacher and former biologist whose expertise is crucial in solving the mystery of Astrophage. JONATHAN OLLEY/COURTESY AMAZON MGM STUDIOS

The effects are mostly practical. Obviously CGI for things like the exteriors of the spacecraft and all that, but almost all of Rocky you see is a puppet. It took six people to operate him, and there were multiple versions of them. Some are robotic, for things that you can't do with puppeteering.

I don't think anything indoors on the *Hail Mary* is ever a green screen. I mean, out the windows, where there's space and stuff like that, but yeah, it's heavily practical. These were huge sets. Like, four sound stages full of just sets. It was really impressive.

***Astronomy*: Is there any other aspect of writing this story that you'd like to talk about?**

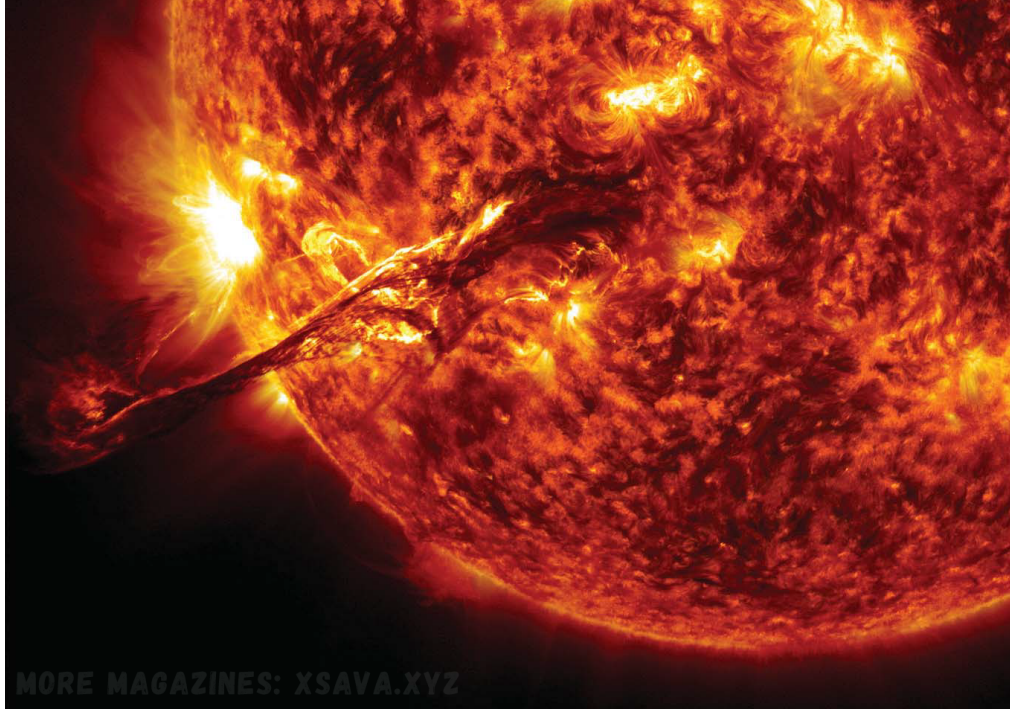
Weir: One of the things that always bothers me in science fiction with first contact stuff is, why are there alien species all so close to each other? The Milky Way is 100,000 light-years across, Tau Ceti is 11.9 light-years away, 40 Eridani is 16 light-years away. I mean, these are next door.

So what are the odds that life would separately evolve on each of these three locations? Because Adrian [Astrophage's homeworld around Tau Ceti], Erid [Rocky's homeworld], and Earth are all worlds that have their own biospheres. How can that happen? The way I solved it was a panspermia event from Adrian. So, some ancestor of Astrophage seeded out in all directions, and some of them ended up landing on Earth, and some landed on Erid, and probably hit everything all over the place, but only Earth and Erid ended up to be [hospitable] enough that it could survive and reproduce. And then evolution took over from there. That all happened 4 billion years ago, so that allowed me to go, okay, there was only one genesis event. Life only evolved once, instead of three times all right next to each other. It happened to not be here on Earth, but it evolved once, and then it seeded here, and then that also made it so much easier for me, because the cellular biology of Eridians [Rocky's species], Astrophage, and humans are all pretty much the same. Because that all evolved on Adrian.

***Astronomy*: This is more of a comment, but Rocky arrives at Tau Ceti with extra fuel because the Eridians don't know about relativity. And I thought having a character who didn't know about that was a really cool way to demonstrate the difference between Newtonian physics and relativity.**

Weir: Oh, thanks. That wasn't the reason I did it. First off, I like to say, ignore the tropes. Question every trope. And so what if for once, we met aliens and we're the advanced ones? And I also thought of how things worked in the real world — let's say when Asians and Europeans started really trading for the first time. The technology trees of those two different chunks of humanity were vastly different.

And so I was thinking that with the Eridians and the humans. I figured, it's not like one species is gonna be better at everything. Eridians invented much better materials technology. Xenonite [the Eridians' composite material] is this kind of magic stuff that I didn't even bother to explain. And then humans invented computers. Eridians have much better analytical brains, they can do complex math in their head, so they never had to invent computers. But humans invented computers initially to do math, and then it turns out you can do a whole bunch of really cool stuff with computers that leaves Eridians in the dust. They also never discovered radiation, because they're completely shielded from radiation on the surface of their planet.


MORE MAGAZINES: XSAVA.XYZ

↑ Humanity discovers Astrophage after it has infected our Sun, causing it to dim — with dire consequences for life on Earth if no solution is found. NASA'S GODDARD SPACE FLIGHT CENTER

The main reason was because I wanted to make sure Rocky had enough fuel for Ryland to go home. So, they had enough fuel for a round trip, but how do I explain why he has an extra 2 million kilograms [4.4 million pounds] to give Ryland? Well, if you incorrectly calculate the travel time and distance and everything for Newtonian physics, you end up thinking you're going to need a lot more fuel, so you end up with a huge excess.

So by doing this, I can demonstrate that our technologies are variable as to who got what, and then also allow Ryland the fuel to go home. Which allowed me to get to that plot point where Ryland had to decide whether or not to sacrifice his life to save Rocky.

***Astronomy*: Which is a very important plot point.**

Weir: My brother from a rocky mother.

For additional content, read the online version of this story on Astronomy.com.

Alison Klesman *is senior editor of* Astronomy.

A palace on the Moon

Image by Tianyao Yang

THE LUNAR ECLIPSE of Sept. 7/8, 2025, was not favorable to observers in the Americas or Europe, but was well-placed for viewers in Asia. Tianyao Yang took the opportunity to capture the silhouette of the Chinese space station Tiangong (or "heavenly palace") as it crossed the Moon during the eclipse.

The International Space Station has previously been captured in transit across a Moon in Earth's shadow, notably by astrophotographer Thierry Legault during the Sept. 28, 2015 eclipse. Yang decided to do the same for Tiangong — and to distinguish his image by blending the transit sequence with a high dynamic range (HDR) capture of the Moon, retaining detail in the umbra, the deepest part of Earth's shadow.

To plan the shot, Yang started with the orbital parameters of Tiangong, published by the China Manned Space Agency in Orbital Ephemeris Message (OEM) format. Yang used the mobile app Planit Pro to convert the OEM data into the more common two-line element (TLE) format and visualize the path of the space station across the eclipsed Moon. "With this information," he says, "I only needed to select an observing site with favorable seeing conditions" — which wound up being outside the city of Chifeng, China.

There was another consideration: "I deliberately chose a spot slightly offset from the central transit line," says Yang. "This way, the station's silhouette would pass across the brighter portion of the eclipsed Moon, avoiding the darker umbral region where the track could have been less distinct or incomplete."

The resulting sequence comprises 22 frames across just 0.72 second — scarcely perceptible in video, but leaving a strong impression in an image.

— Mark Zastrow

Sept. 8, 2025, 12:57 A.M. local time • Chifeng, Inner Mongolia, China
Sony a1 • 600mm lens with 2x teleconverter
22-frame sequence of 1/2000-second exposures at f/8 and ISO 1600

GET READY TO PARTY UNDER

THE STARS

If you take a little time to prepare, your next star party will be a blast! BY KEN WILSON

Some people may think that the words *astronomer* and *party-animal* don't go together. Nonetheless, for many astronomy enthusiasts, star parties are the social highlight of the observing season.

Star parties are informal gatherings of amateur astronomers that let them share the night sky and their telescopes with the public and other observers. They can range from a few hours at a local park to week-long events held at distant dark-sky sites. They are usually sponsored by a local astronomy club, museum, or park. You can bring your own telescope or look through those of others.

There are a few things you need to decide and prepare for before you head out for the starry skies and join the fun, so if star parties are new to you, read on for advice on getting the most from your first one. The motto "Be prepared" is not just for scouts. It applies to amateur astronomers, too!

Preparations

First on the list is to find out as much as you can about the star party that you plan on attending. Major star parties will likely have a dedicated website or Facebook page. If it's a smaller affair hosted by a local club or museum, look for details posted on the sponsor's website.

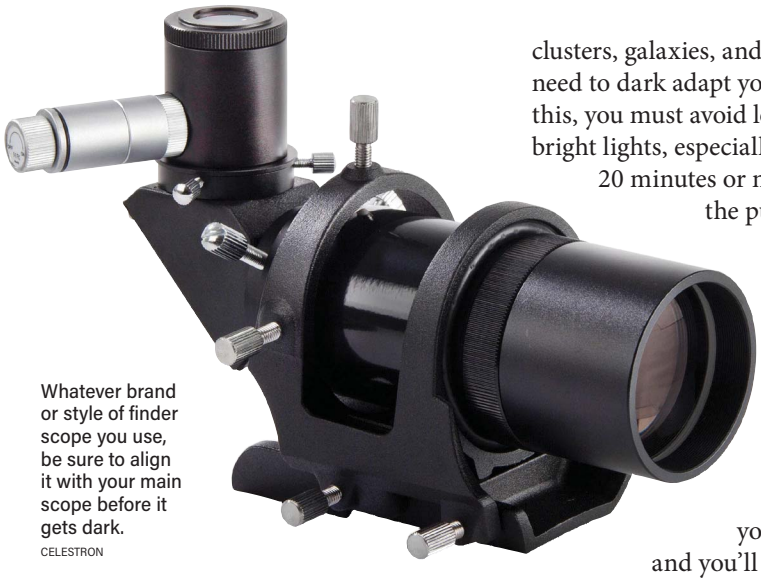
Key information to look for includes location, dates, times, fees, registration requirements, camping information, food service, program details, weather contingencies, and star party rules. Pay careful attention to the rules and deadlines for registrations. If you know anyone who's previously attended the star party, ask them to share their experiences and any tips or suggestions.

If the star party location is reasonably close to you, consider making a pre-visit during the daytime. By checking it out before you go, you can locate the viewing site, parking, and important amenities like restrooms or porta-potties.

If you're bringing a telescope or camera gear, make sure you take the time to make a thorough checklist of things to bring. (Believe me, it's no fun to haul a telescope hundreds of miles to a star party only to find that you forgot to bring eyepieces.) One way to do this is to assemble your setup at home well before the star party. Make a detailed list of every item that you'll need in order to use your telescope

LEFT: Star parties, like this one held in a national park in Idaho in 2017, can be wonderful social events. Just be sure you're ready to attend. CRATERS OF THE MOON NATIONAL MONUMENT AND PRESERVE/NPS/JACOB W. FRANK

RIGHT: Your observing kit should contain everything you need for each session. This kit, housed in a large fishing tacklebox, has enough space even for items only needed occasionally. Eyepieces are in a separate padded case. *ASTRONOMY:* MICHAEL E. BAKICH



Whatever brand or style of finder scope you use, be sure to align it with your main scope before it gets dark. CELESTRON

— for example, telescope tube, tripod, mount, eyepieces, counterweights, slow motion cables, finder scope, batteries, electronics, and manuals. And don't forget any tools needed to assemble or adjust your gear. If you use a star atlas or guidebook, put it on the list, too. You can reuse the same checklist when you pack up to go home so you don't leave anything behind. If this is going to be your first star party, you may even want to leave your telescope at home and just soak up the experience and enjoy views through other people's scopes.

Light advice

The most important piece of gear to bring along is a red flashlight and spare batteries. By "red," I mean one that gives off red light instead of white light.

To best see faint stars, star clusters, galaxies, and nebulae, you need to dark adapt your eyes. To do this, you must avoid looking at any bright lights, especially white light, for 20 minutes or more. This allows the pupils of your eyes to open to their widest and the photosensitive chemicals in your retinas to build up. Exposure to any bright light will spoil your dark adaption and you'll have to start all over again.

But you will need at least some light to be safe and to see star charts and equipment. Research shows that red light is the least damaging to night vision, so a good red flashlight is the astronomer's best friend. Get one that's only as bright as needed for reading a chart or safely moving around at night.

A dimmable red light is best. Some off-the-shelf flashlights include a red or night vision setting, but avoid those that force you to click through one or more white light modes before you get to the red. Instead, look for one with a separate switch for just the red mode.

LEFT: If you'll be staying at a star party during the day, be sure to bring and use sunblock. DAVID CHANCEY/WIKIMEDIA COMMONS

BOTTOM LEFT: The Starlite by Rigel Systems is a good choice for an observing light. It has two red LEDs and is dimmable over a nice range. *ASTRONOMY*: MICHAEL E. BAKICH

BOTTOM RIGHT: A great choice for an observing light is the Wayllshine Red LED Flashlight. Although the light in this image appears yellow, in reality it is intensely red. *ASTRONOMY*: MICHAEL E. BAKICH

You can also red-shift a white flashlight by covering the lens with dense red plastic such as the clear red tape sold in auto parts stores for temporary repairs of broken taillights. In a pinch, you even can use a brown paper bag to both dim and redden a white flashlight. There are also red cellphone flashlight apps you can download. But use any flashlight sparingly during a star party, and be careful to not shine it directly into someone's eyes or telescope.

Speaking of white-light no-nos, be sure to cover or switch off any white lights in your car so that opening doors doesn't destroy the night vision of fellow stargazers. That brings us to the tricky issue of external car lights: Make sure that you arrive at the star party before it gets dark so that your headlights don't spoil the observing. If for some reason you arrive after dark, try to park away from the telescopes where your headlights won't shine on observers. If you think you may need to leave before dawn or before the star party officially ends, again, park where your headlights or taillights will not blast the observing area. (Of course, in any case, safety must take priority. If you must turn on white light for an emergency or to safely drive your vehicle, do so.)

Another light source people sometimes forget are device screens. Laptops, tablets, and cellphones are handy tools, but their bright screens can ruin your night vision in a flash. So, before it gets dark, lower the screen brightness as much as possible and see if you can

change the screen background to black and text color to red. For laptops, adapt a suitable-sized plastic bin or cardboard box to restrict light to a single direction. Painting the box's interior with flat black paint is a big help.

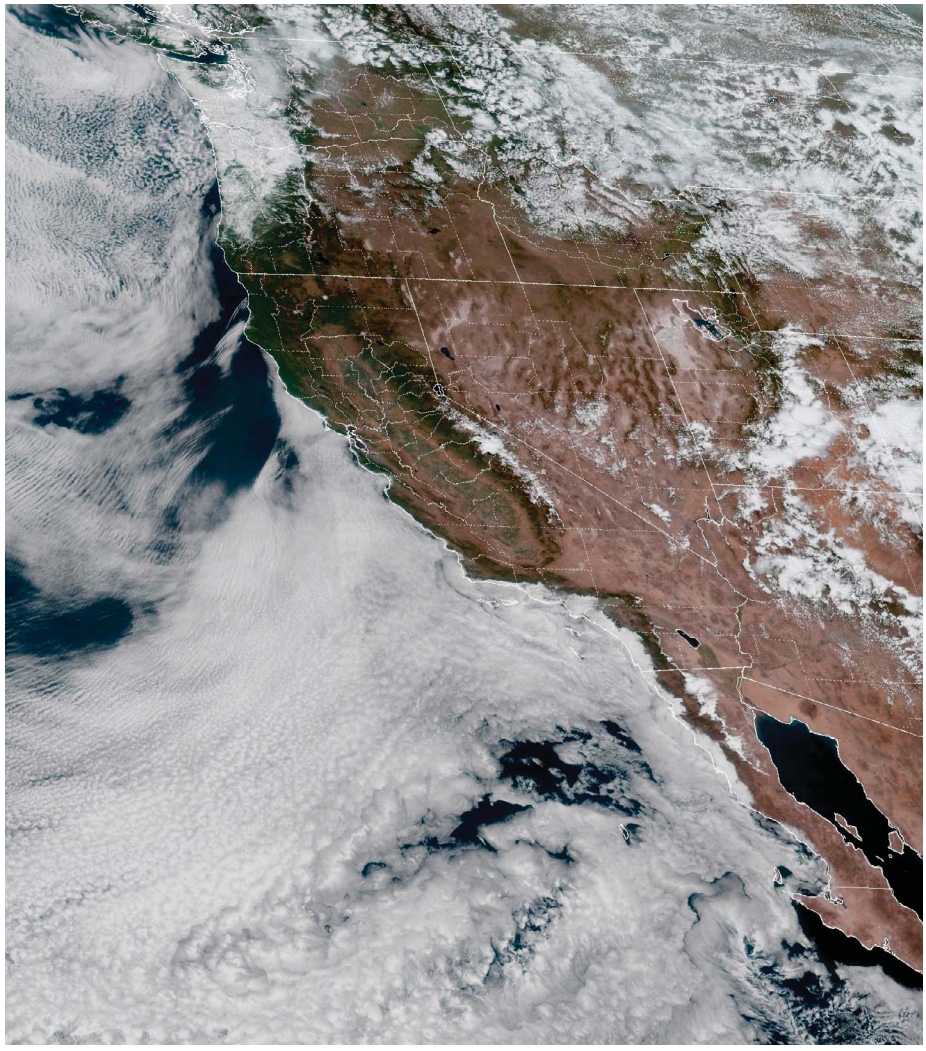
Beyond clear skies

It's important to be prepared for the weather at a star party. Always check the latest forecast. If a hurricane or severe thunderstorm is on its way, you might want to reconsider plans to attend. In some cases, the hosts may even cancel it, so stay informed.

Also check for predicted nighttime temperatures. Even if daytime temperatures are quite warm, once the Sun goes down, it can cool off quickly. Be sure to bring gloves, hats, and extra layers. Simple sneakers may not be enough to keep your feet warm; you may want to consider bringing insulated boots.

Don't plan on warming up in your car with the engine running, as the fumes will annoy your fellow stargazers. You'll find that small disposable charcoal-and-iron hand warmers sold for campers and hunters come in handy for frozen fingers — and also to remove dew from telescope optics. There are rechargeable electric handwarmers available, as well.

Besides the cold, be prepared for rain and dew. Bring along plastic tarps or plastic garbage bags so that you can quickly cover your telescope and other gear if a sudden shower pops up. If you observe where dew can form on your optics, invest in telescope dew heaters or a battery powered car window defroster to chase the damp.



Satellite maps of the area where a star party will be held can show current clouds. Many sites and smartphone apps also offer animations that let you see the directions the clouds are moving. CIRA/NOAA

Other tips

In addition to weather, be prepared for the creepy crawlies. Depending on where you stargaze, these could be mosquitoes, flies, spiders, scorpions, ants, or ticks. To avoid the latter, don't set up in tall grass or brush. A good insect repellent comes in handy for star parties. Be careful, however, with DEET-based repellents: DEET may damage plastics, rubber, paint, ink, and certain coatings.

If your star party is more than a one-night stand, be sure to bring sunblock. And personal comfort is important. Bring snacks, a thermos of a hot or cold beverage (no alcohol), and some toilet paper — just in case. If you plan to spend more than one night at the star party, be prepared to camp out. A few events may offer cabins or a bunk house, but they are the exceptions. Even if you plan to sleep in your vehicle, you'll need blankets, food, and nonalcoholic beverages.

Set up your equipment before it gets dark. This allows you to align your finder telescope on distant trees or utility poles, review your object lists, and collimate your optics if you have a reflector. If you're having problems with setup, feel free to seek advice from others, but keep in mind they may initially be busy setting up their own gear.

As a courtesy to others, don't play music during the star party. Not all astronomers share the same taste in music, and most enjoy the vibe of nature's nocturnal sounds. Likewise, if you must smoke or vape, please be considerate of others by doing it downwind.

After setup, feel free to wander by the other telescopes and socialize. Amateur astronomers are a friendly bunch. But it's best to ask permission before looking through someone else's scope, and you should avoid touching equipment without the owner's OK. Typical questions you might ask include, "What are you looking at?" and "What kind of telescope is this?" or "What power/eyepiece are you using?" Be especially careful where you aim your red flashlight, especially if someone is imaging.

If you follow these guidelines, your evening under the stars should be heavenly and hassle-free.

Ken Wilson *is a longtime observer and imager who has been to many star parties during his time on this planet.*

HALLEY'S COMET
THROUGH THE AGES

For more than two millennia, humanity has watched this celestial wonder. BY BEN EVANS

EARLY IN 1986, a visitor from deep space graced Earth's skies, and for a few breathless weeks human eyes were snatched from their daily labors and fixated on the heavens. The object of this transitory public veneration was Halley's Comet — the most famous, easily recognizable, and beloved of celestial wanderers. This icy interloper, officially known as 1P/Halley, revisits the inner solar system every 72 to 80 years.

Aggregated lumps of frozen water and gases mixed with smaller amounts of rock and dust, comets originated in the solar nebula, from which the Sun and its planetary retinue formed, some 4.5 billion years ago. Their highly eccentric orbits periodically carry them to the outer solar system and back toward the Sun. There they undergo drastic heating and outgas chemical volatiles, which produce a short-lived extended atmosphere around the comet's nucleus and sometimes a spectacular, shimmering tail of gas and dust in its wake.

Long-period comets, thought to originate in the Oort Cloud at the solar system's ragged extremity, require thousands or even millions of years to circle the Sun. But short-period comets, like Halley, are believed to arise in the Kuiper Belt, just beyond the orbit of Neptune. Their orbital periods span a few years to a few centuries.

Comets' inherent smallness, iciness, and extreme distance from the Sun make them unique in the solar system. They suffered none of the volcanic tumult, tectonic upheaval, or violent collisions that blighted the Sun's inner planets or their

LEFT, TOP: This image of Halley's Comet was taken Mar. 8, 1986, as part of the International Halley Watch Large Scale Phenomena Network. NASA/W. LILLER

LEFT, BOTTOM: Comet Halley was photographed at Yerkes Observatory on May 29, 1910, nine days after it passed closest to Earth. YERKES OBSERVATORY

RIGHT: The Bayeux Tapestry records the appearance of Halley's Comet in 1066. The phrase *Isti Mirant Stella* translates as "they wondered at the star." MYRABELLA/WIKIMEDIA COMMONS

This Chinese text documents the first recorded sighting of Halley's Comet. In part, it reads, "In the seventh year of Emperor Qin Shihuang of the Warring States, a broom star first appeared in the east, then it appeared in the north." XU, ZHENTAO, DAVID W. PANKENIER, AND YAOTIAO JIANG/WIKIMEDIA COMMONS

moons. Comets remain geochemically unaltered relics from the solar nebula — pristine looking-glasses, snapshots back to the dawn of time.

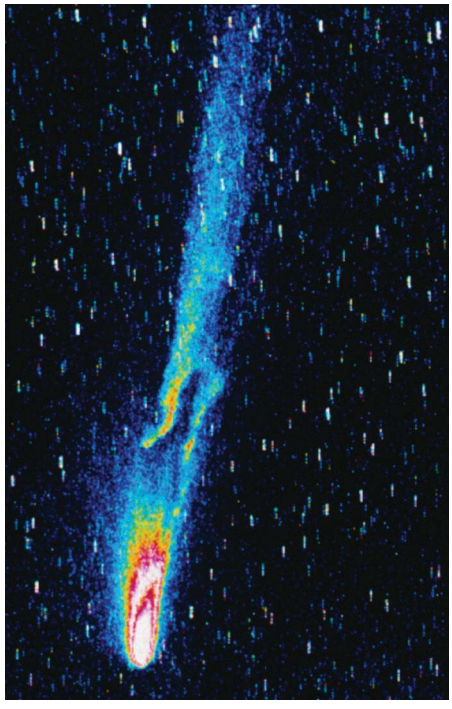
But until a few centuries ago, they were regarded quite differently, feared and revered through history as harbingers of doom. For millennia, our forebears recorded Halley's visitations on baked clay tablets, on wax-coated wooden boards, on papyrus, on parchment — and with their own terrified eyes.

Previous visits

Halley's Comet was first mentioned by the Chinese in 240 B.C.E., appearing in the east, then progressing northward. In other apparitions it was visible "day beyond day" for weeks. Variously described as sparkling, bluish-white in color, and with flaming red rays, one annalist compared its nucleus to the eye of an ox, its fan-shaped tail "like that of a peacock."

To our ancestors, comets presaged calamity. The Chinese — assiduous keepers of records — omitted mentioning one visitation, lest it inadvertently cast the "good" reign of Emperor Wen of Han in a dim light. Halley later appeared "like a sword" over Rome in 11 B.C.E., portending the death of the great general Marcus Vipsanius Agrippa. And the Jewish historian Josephus saw Halley's appearance in 66 C.E. as heralding the destruction of Jerusalem four years later.

Another apparition, "a very fearful star," wrote historian Dio Cassius, prophesied the murder of the Roman emperor Macrinus in 218 C.E. Its closest recorded approach to Earth, just 3 million miles (5 million km) in 837 C.E., brought Louis the Pious, king of the Franks, to his knees in fearful penance. Halley's tail stretched halfway across the sky and at magnitude –3.5, its visual brilliance rivaled Venus for six weeks — a truly awe-inspiring spectacle. Halley also appeared before the defeat of Attila the Hun in 451 C.E. Ireland's *Annals of Ulster* noted its 989 C.E. visitation propitiously came during "a dark and rainy year." And Halley pops up memorably in the Bayeux Tapestry, foreshadowing William the Conqueror's 1066 invasion of England.



This image of Halley's Comet combines six exposures in different wavelengths taken with the wide-field CCD camera at the European Southern Observatory on March 6, 1986. ESO

As recently as 1910, people left doors unopened and refused to drink water when Halley was in the sky, fearing the comet's "pestilential vapors" might pour down to Earth. In the West, spectroscopy had revealed the toxic gas cyanogen in the comet — inducing terror that it might snuff out life on Earth. People panic-bought gas masks and "anti-comet pills" to protect themselves.

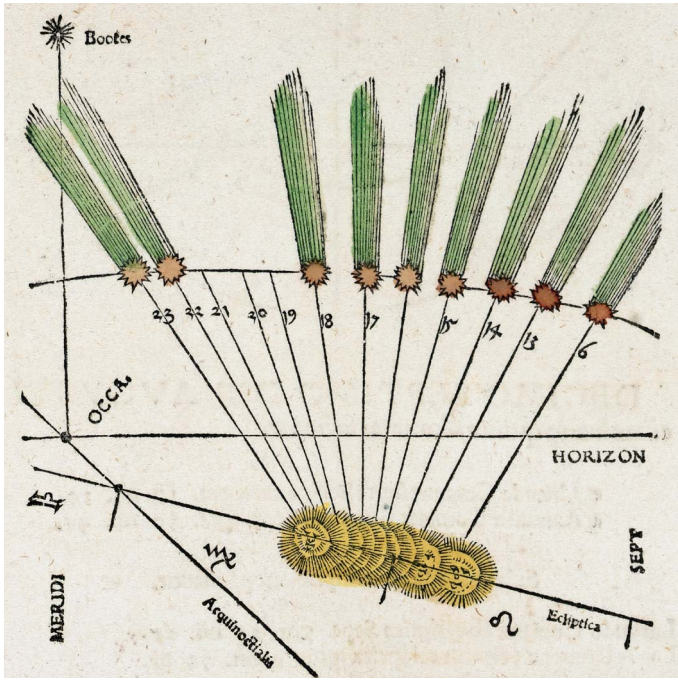
Conversely, others regarded Halley as symbol of divine approval. It may have inspired the Mongol warrior Genghis Khan's conquests and precipitated the Ottoman Empire's invasion of Hungary. In 1456, Emperor Zara Yaqob of Ethiopia was sufficiently inspired by the comet to found Debre Berhan, the City of Light, as his imperial capital.

The U.S. satirist Mark Twain, born two weeks before Halley's 1835 visitation, caustically noted in 1909: "Now here are these two unaccountable freaks; they came in together, they must go out together." His self-prophecy proved accurate: Twain died in 1910, one day after Halley reached perihelion, its closest point to the Sun.

The great one

Before the 17th century, it was assumed comets made singular passes through the solar system. But after observing Halley's 1682 visitation, English astronomer Edmond Halley computed data from comets seen in 1531 and 1607 and found all three moved in virtually identical orbits, separated by intervals of about 75 years. Halley concluded the three observed comets were one and the same.

Although he correctly predicted it would return in 1758, Halley didn't live to see it, dying in 1742. The comet was first seen by German amateur



ABOVE LEFT: Giotto di Bondone's painting, *The Adoration of the Magi*, shows a cometlike object, supposedly the Star of Bethlehem, above the earthly scene. Because Halley's Comet appeared in 1301 and Giotto created this work of art in 1305, art historians think his observation of the comet influenced the shape of the "star." WIKIMEDIA COMMONS

ABOVE RIGHT: *Astronomicum Caesareum*, a work by Petrus Apianus, shows this illustration, thought to be the 1531 appearance of Halley's Comet. Note how it correctly portrays the comet's tail always pointing in the direction opposite the Sun. NATIONAL LIBRARY OF POLAND/ WIKIMEDIA COMMONS

astronomer Johann Palitzsch on Christmas Day 1758, and a year later was named in Halley's honor, designated 1P/Halley — the first-known periodic comet.

In 1910, Halley was photographed for the first time. Then, in 1986, its most recent visitation saw a concerted international campaign to explore the comet.

It was first seen on its approach to the inner solar system in October 1982, using the 200-inch Hale Telescope on Mount Palomar. The first visual observations came in January 1985, and Halley was dimly visible to the naked eye the following November. It achieved perihelion on Feb. 9, 1986, and reached its closest point to Earth on April 10.

But despite much media hype, Halley proved dismally unspectacular. Observers with hopes of seeing a great ball of flame traversing the sky instead beheld a tiny, uninspiring pinprick of light. Urban light pollution did not aid matters, although binocular observations near the horizon at dawn or dusk achieved some success.

Halley approached no closer than 39 million miles (63 million km) from our planet, almost half the distance between Earth and the Sun, and its magnitude peaked no higher than 2.6. It scored among the comet's most visually unfavorable showings in recorded history.

But one person who did see Halley that spring was Japan's emperor, Hirohito, who observed the comet as a young boy in 1910 and again, aged 84, from the roof of his imperial villa. "I am fortunate that I could see it twice in my life," the emperor said at the time. "I'm very happy that I could see clearly the comet with its gas tail."

The Halley Armada

Halley's lackluster display was compensated by the success of the Halley Armada: a close-range reconnaissance by five space probes from the Soviet Union, Japan, and the European Space Agency (ESA). Three U.S. probes viewed Halley from afar. But hopes to observe the comet from the space shuttle were curtailed by the January 1986 Space Shuttle *Challenger* tragedy.

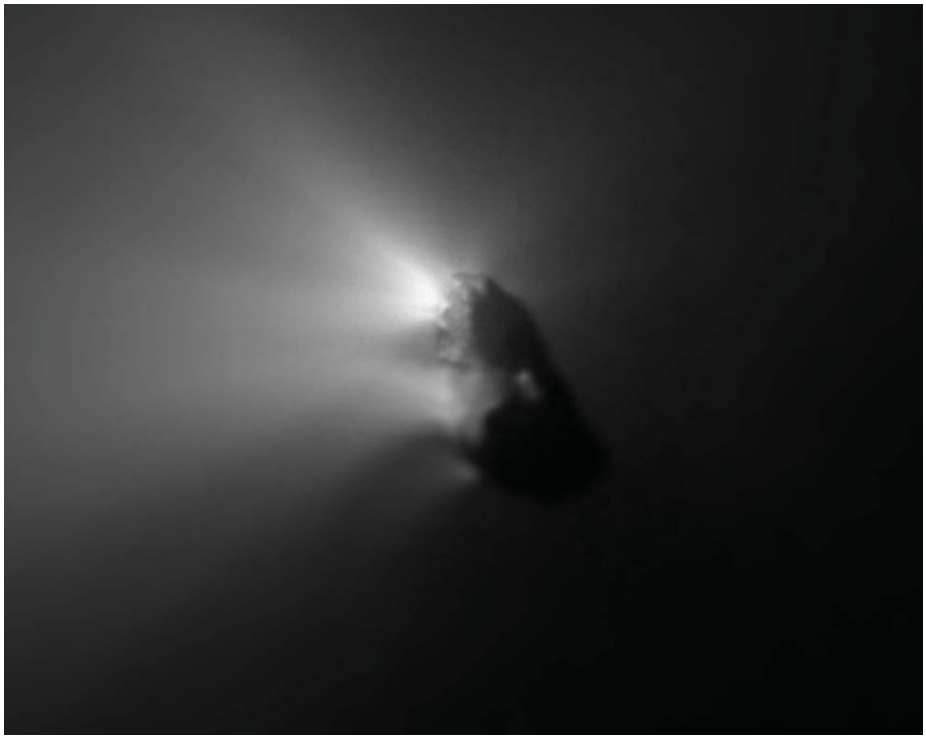
First to reach the comet was the Soviet Vega 1. Launched in December 1984, it delivered an atmospheric balloon and lander to Venus in June 1985, then headed to intercept Halley. On March 6, 1986, Vega 1 flew within 5,523 miles (8,889 km) of the nucleus.

It found two bright regions in what was initially suspected to be a double nucleus, but which turned out to be a pair of active jets outgassing cometary material into space. The results proved surprising: with an albedo of 4 percent — meaning it reflected 4 percent of incident sunlight — the nucleus was significantly darker than anticipated: blacker, in fact, than coal.

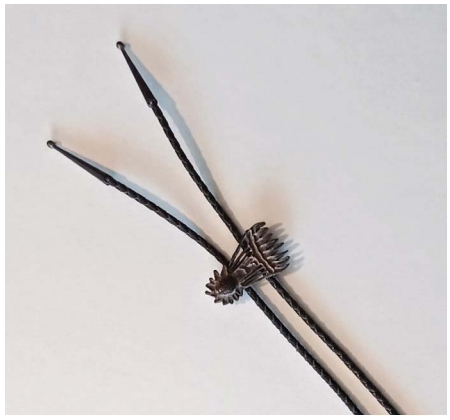
Infrared data pegged its temperature at 300 to 400 kelvins (80 to 260 degrees Fahrenheit [27 to 127 degrees Celsius]), far warmer than expected for such an icy object. This had the effect of shifting opinions of Halley's nature from a "dirty snowball" to a "snowy dirtball." Ten percent of the nucleus was highly active, with icy regions thickly coated in dust. It measured Halley's nucleus at 8.7 miles (14 km) long.

But Vega 1 was savagely pummeled by dust particles — some 4,000 impacts per second — during its 177,000 mph (285,000 km/h) flyby, disabling two scientific instruments and reducing solar array capability.

Two days later, Japan's Suisei ("Comet") probe swept within 93,830 miles (151,000 km) of the nucleus. Its ultraviolet imager refined the nucleus' rotation rate and measured interactions between Halley and the solar wind.



On March 14, 1986, ESA's Giotto spacecraft imaged outbursts from the nucleus of Comet Halley from a distance of about 1,240 miles (2,000 km). ESA/MPS



ABOVE: This bola tie with a solid silver slide, made in 1985 and modeled after historical representations of Halley's Comet, is just one of thousands of Comet Halley mementos. *ASTRONOMY*: MICHAEL E. BAKICH

BELOW: When Earth passed through the tail of Comet Halley in 1910, many people panicked because astronomers had discovered highly toxic cyanogen in its tail. Unscrupulous businessmen marketed worthless "Comet Pills" to the public. This bottle was sold in 1985 as a comedic reminder of that era. *ASTRONOMY*: MICHAEL E. BAKICH

Eighteen hours after Suisei, on March 9, Russia's Vega 2 passed within 4,990 miles (8,030 km) of Halley and took 700 photographs. It achieved better resolution than Vega 1 thanks to reduced dust concentrations. And on March 11, Japan's Sakigake ("Pioneer") sped past the comet at a distance of 4.34 million miles (6.99 million km).

Giotto's triumph

But it was ESA's Giotto that achieved the closest-ever flyby of the comet: just 370 miles (596 km) on March 14, 1986. (The spacecraft was named for the Florentine Renaissance artist Giotto di Bondone, who observed Halley in 1301 and used it as inspiration to paint the Star of Bethlehem in his masterpiece, *The Adoration of the Magi*.)

To achieve such close distances, Giotto relied heavily on the Vegas. Without their data, it likely could not have approached Halley much nearer than 2,500 miles (4,000 km). "The Vegas were our pathfinders," said Giotto deputy project scientist Gerhard Schwehm in a retrospective interview with ESA. "Images from their cameras allowed us to determine very accurately the position of the comet and the trajectory we wanted Giotto to follow."

That Giotto survived was no small miracle: It sustained 12,000 dust impacts, yet returned 2,112 images of the nucleus — the clearest Halley pictures ever taken. Seconds before closest approach, a particle tinier than a half-grain of rice hit the spacecraft, knocking its Earth-facing antenna out of alignment and crippling Giotto's multicolor camera.

Hearts on the ground fluttered and computer screens went ominously blank. But after 32 tense minutes, Giotto stabilized itself and contact resumed. "We thought something might happen, because of the dust environment," Schwehm told ESA. "The frequency of dust impacts was building up and we knew that this could cause us to lose contact."

Giotto revealed the elongated nucleus, not unlike a peanut or an avocado, dotted with hills and depressions. Multiple jets on Halley's sunlit side copiously outgassed water, carbon monoxide, methane, ammonia, and other hydrocarbons at a rate of 3 tons per second. Dust sizes approximated cigarette-smoke particles. The fluffy, porous nucleus was a third less dense than water.

The ESA team celebrated that night, eating Giotto-shaped chocolates from a local baker. But the Halley Armada was not yet done. NASA's International Cometary Explorer (ICE) flew directly through Halley's tail, gathering solar wind data. Pioneer 7 measured interactions between the tail and the solar wind. And the Pioneer Venus Orbiter, which had circled Venus since 1978, observed that Halley outgassed 270 million tons of water during its 1986 perihelion passage.

With each visitation to the inner solar system and each new perihelion, Halley will continue losing material. It has been in its present orbit for at least 16,000 years. In December 2023, it reached the furthest point in its solar orbit, about 3.3 billion miles (5.3 billion km) from the Sun. It now has begun the long, lonely inbound journey toward its next perihelion in July 2061.

What new discoveries will it bring with it? Only time will tell.

Ben Evans, *a space and astronomy writer, was fascinated to see Halley's Comet in 1985–86 when he was nine years old.*

Astronomy

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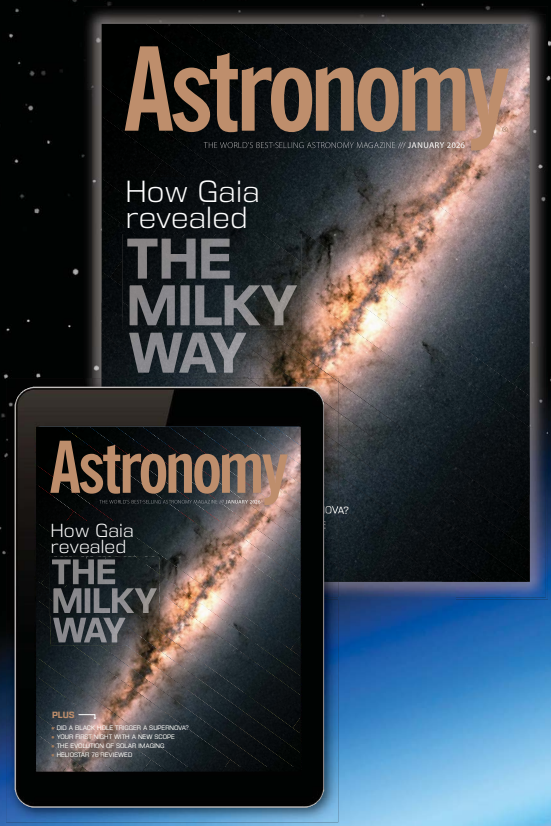

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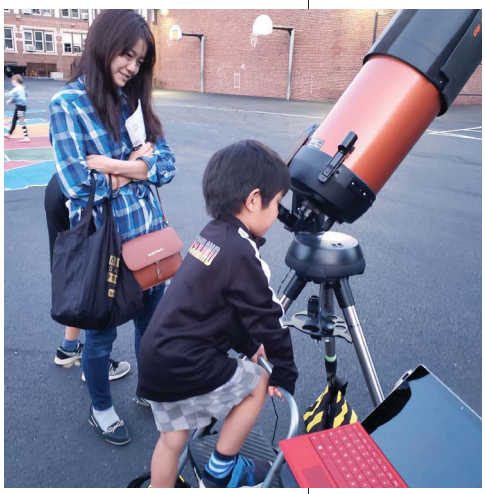

ABOVE: The author set up her scope in a cul-de-sac near her apartment in Beavercreek, Ohio, on Sept. 20, 2016, to target Saturn in the western sky. MOLLY WAKELING

ABOVE, RIGHT: On June 10, 2019, the author, as part of the Miami Valley Astronomical Society, conducted a public observing session from the parking lot of the Wright Memorial Library in Dayton, Ohio. MOLLY WAKELING

BY MOLLY WAKELING
Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.

Spring is here and with the evening air growing warmer, it's finally time to get back outside and enjoy the stars. It's also a good time to team up with your local astronomy club or other interested observers and host some public outreach nights. As much joy as we get from looking through telescopes, that joy is multiplied when shared with others — particularly people who have never looked through an eyepiece before.

Guidelines

First, you must find a good place to host the event. A state or county park a little outside of town is ideal for darker skies, but sometimes you need to go to the people. My former astronomy club in Dayton, Ohio, frequently held events at local breweries, school parking lots, city parks, and sports fields. Aim for a spot with few overhead lights, or sometimes you can ask the property manager to turn them off. If there are no other options, put something between you and the lights, like a building. Wherever you end up, use cones to separate parking and observing areas to reduce disruptive headlights — and risk to people and equipment from vehicles moving in the dark. At our state park observing nights (our highest-attended, thanks to the nearby campground), we usually had a club member in a vest directing traffic.

Having a variety of telescopes both is fun and helps get more observers involved. Dobsonians are excellent for public nights because they're quick to set up and easy to use. However, I frequently bring my go-to alt-azimuth mount with an 8-inch Schmidt-Cassegrain, and I often let the kids excitedly push the "go" button to slew to the next target. Binoculars are excellent, especially if they're on a parallelogram mount to quickly adjust for differences in height. Laser pointers or bright flashlights with narrow beams are useful as well for pointing out where we're looking in the sky and sharing constellation lore while people wait in line.

Use red lights or glow-in-the-dark tape to mark tripod legs and other tripping hazards. A stepstool with some kind of handle or bar is great for small children and an excellent way to prevent people from grabbing the eyepiece. Choose eyepieces with large exit pupils and eye relief, even if it's not the ideal magnification, because people will have a much easier time getting their eye lined up with them — and they can even keep their glasses on. Don't forget to bring spare batteries for Telrads and any other devices.

Having a variety of telescopes both is fun and helps get more observers involved.

Pick the winners

Choose bright and visually appealing targets. While amateur astronomers love to hunt down faint fuzzies, the public generally won't appreciate them. Planets and the Moon are perfect targets with a huge "wow" factor. Even though we see the Moon all the time, witnessing the shadowed edges of craters up close is an entirely new experience for newbies. Open clusters, globular clusters, double stars, and bright nebulae such as the Dumbbell (M27), Ring (M57), and Orion (M42) are popular deep-sky targets. Both kids and adults are also fascinated just seeing a single bright star, like Vega or Sirius.

While people are in line and taking turns, describe what it is they're looking at. I like to first tell people what they should look for ("a small gray circle," "a cloud of stars," "spiral arms"), and then more details about what it is. What kind of object is it? How far away? How large? Is it in our galaxy? How was it formed? What's happening inside?

These are the ingredients for a perfect public outreach night. Now get out there and share the joy of the night sky!

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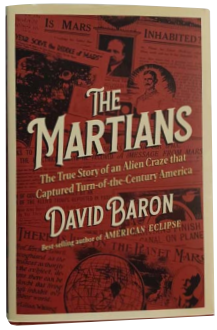
Little green men?

Liveright Publishing
New York, New York



David Baron, author of *American Eclipse*, has produced another compelling read. *The Martians* chronicles the public's fascination with alien life at the turn of the 20th century. This 322-page book will teach you a lot about the people who created the martian craze and society's response to them.

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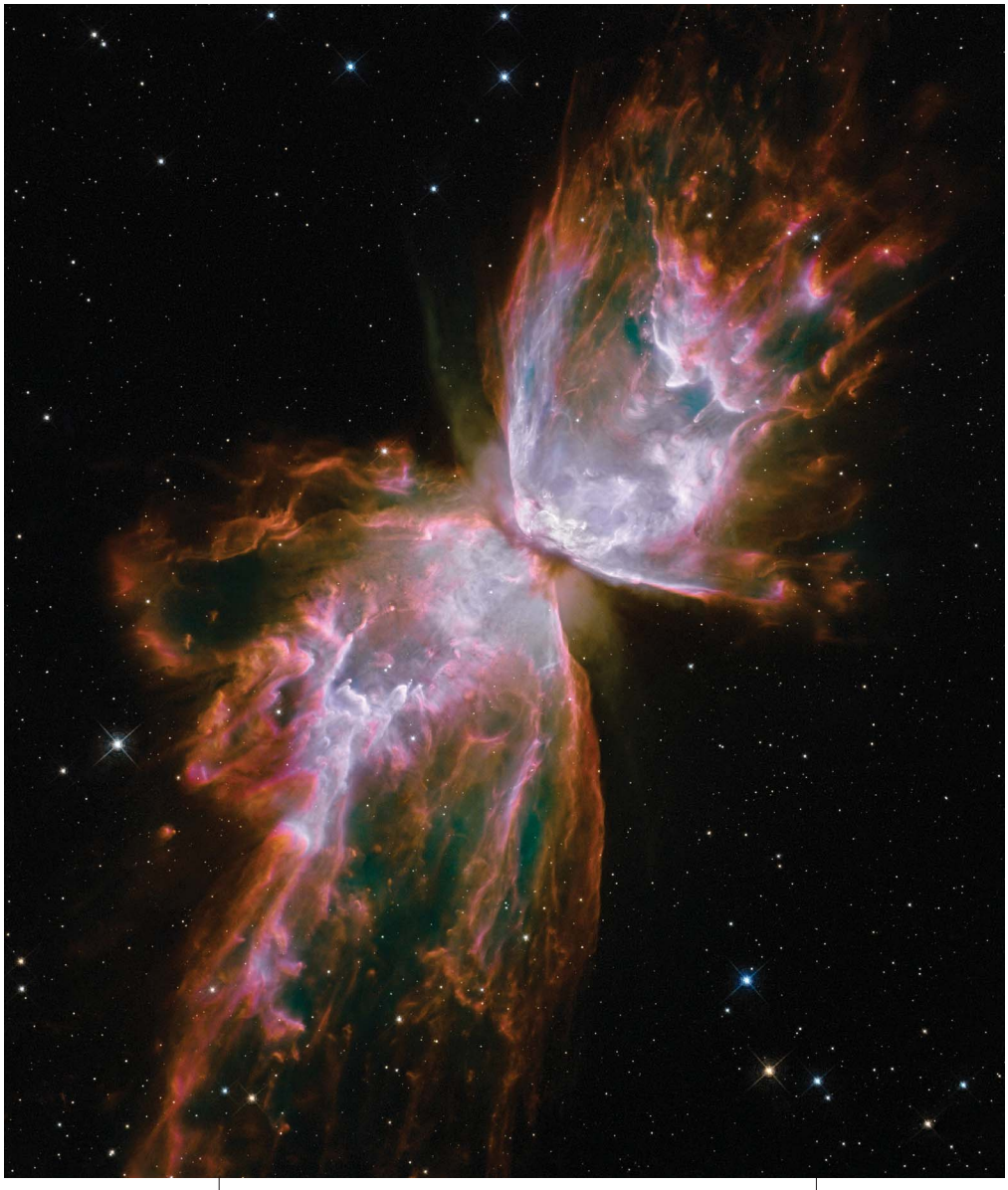


Planetary nebula NGC 6302, also called the Butterfly Nebula and the Bug Nebula, lies in the Milky Way, about 3,800 light-years away in Scorpius. At around 2,200 years old, NGC 6302 is relatively youthful. NASA, ESA AND THE HUBBLE SM4 ERO TEAM

Q | HOW LONG DO PLANETARY NEBULAE LAST ON AVERAGE? WHAT ARE SOME OF THE CONTROLLING FACTORS?

Doug Kaupa
Council Bluffs, Iowa

A | To understand how long a planetary nebula remains visible, we first need to understand why a planetary nebula is visible at all. When a solar-type star (one with a mass of 0.8 to eight times that of our Sun) reaches the end of its life cycle, it casts off its outer layers, leaving behind a hot core that emits copious amounts of high-energy ultraviolet rays. The expanding gas shell absorbs the rays, and this absorption leaves the gases in an excited state, meaning that the electrons within the atoms are elevated to higher energy levels. These electrons then emit visible light when they return to their original states. As the gas shell continues to expand, the planetary nebula will remain visible to us until the gases become too diffuse.

The duration of the visibility period will therefore depend on the amount of expelled material, which relates directly to the star's mass; naturally, the greater the mass, the higher the amount of material expelled. The length of time that a nebula is visible also depends on its expansion rate: The faster it expands, the less time it will take for it to become too diffuse to absorb enough energy to glow. Yet another factor is metallicity, or chemical composition. Gaseous shells with a lower metal content tend to be less dense and therefore will become too rarefied to remain visible within a shorter amount of time. (Note: Astronomically speaking, a metal is defined as any element heavier than helium.)

Taking these factors into account, astronomers estimate that a planetary nebula should, on average, remain visible for 21,000 to 25,000 years before its shell is rendered invisible. Keep in mind that this value is an average. Planetary nebulae that expand very quickly and are less dense will vanish sooner, while those that expand more slowly and are of greater density will last longer.

In 2022, a team of astronomers from the University of Hong Kong and the Laboratory for Space Research discovered a planetary nebula in the star cluster M37 that they estimated to be 70,000 years old. (Astronomers can estimate a planetary nebula's age by measuring its expansion speed and extrapolating backward.) This planetary nebula, IPHASX J055226.2+323724, is the oldest of the approximately 4,000 known planetary nebulae in our galaxy. Although it is an outlier, it illustrates the point that some planetary nebulae will last well beyond 25,000 years. It is highly unlikely that any

planetary nebula would remain visible for more than 100,000 years, however.

We can conclude that the planetary nebulae we can see through our scopes (e.g., the Ring Nebula and the Helix Nebula) will remain visible for thousands of years. But compared to the stars that produce them, planetary nebulae are ephemeral entities indeed.

Edward Herrick-Gleason
Astronomy Educator,
St. John's, Newfoundland and Labrador

THERE'S A CLEAR STATED PRIORITY SHIFT SINCE THE FIRST SPACE RACE TOWARD MORE SUSTAINABLE EXPLORATION.

Q ORGANIZATIONS — POLITICAL, SCIENTIFIC, AND COMMERCIAL — ARE SHOWING INTEREST IN GOING TO THE MOON. BUT ALL TRIPS THERE HAVE PRODUCED TRASH THAT HAS NO FUTURE USE AFTER BEING USED ON THE MOON. ARE THERE PLANS BEING MADE BY THESE GROUPS TO ADDRESS THE TRASH PROBLEM?

Mike Sackheim
Evanston, Illinois

A Yes, groups are making plans, but addressing the trash problem on the Moon is surprisingly complex. Currently, organizations are looking at the problem through three different lenses: preservation, mitigation, and recycling.

First, much of the roughly 400,000 pounds (181,440 kilograms) of existing "trash" on the lunar surface from past Apollo missions — all meticulously documented in NASA's *Catalogue of Manmade Material on the Moon* — is now considered human heritage. This designation includes everything from rovers to the more absurd, like bags of human waste left by Apollo astronauts. All of the artifacts left by those missions are protected by the 2020 U.S. One Small Step to Protect Human Heritage in Space Act and will be left in place, memorializing the historic era of early human spaceflight.

Second, there's a clear stated priority shift since the first space race toward more sustainable exploration. International bodies like the United Nations' Committee on the Peaceful Uses of Outer Space, the European Space Agency, and the 55 signees of the Artemis Accords have all placed a heavy emphasis on mitigating the amount of debris created by this new era of exploration, with each organization outlining specific plans for end-of-mission spacecraft disposal.

However, this focus is primarily on minimizing orbital debris. Despite acknowledging the need for waste storage on future crewed and uncrewed missions, agencies like NASA haven't yet outlined concrete strategies for dealing with trash accumulated on the lunar surface.

Given the lack of defined long-term waste storage strategies, the most forward-looking approach is recycling. In a December 2025 paper in *Chem Circularity*, experts assert that sustainable space exploration requires moving beyond the "use and discard" model and toward what they call a "circular space economy." Future missions, they argue, should be designed from the outset to apply the principles of reusing, repairing, and recycling, ensuring that materials are launched once and used indefinitely.

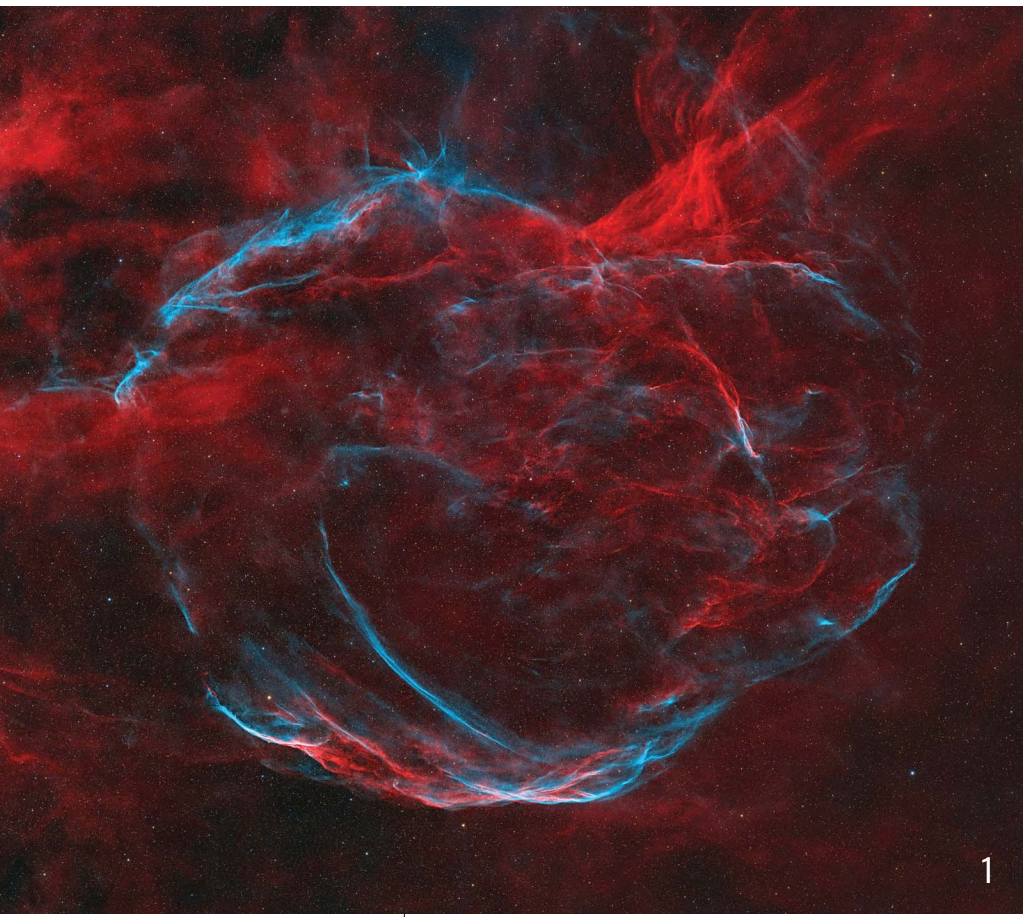
Agencies are already taking concrete steps to make this vision a reality. For example, NASA's LunaRecycle Challenge, which launched its first phase in late 2024, is actively soliciting innovations to transform waste — like the estimated 4,600 pounds (2,100 kg) of trash a four-person crew would generate in a year — into useful resources. By funding technologies that could transform discarded items into water, energy, fertilizer, or even construction components for habitats, initiatives like this are laying the groundwork for a more sustainable future.

Brooks Mendenhall
Staff Writer

A jettison bag — used during the Apollo missions to collect and discard food wrappers, human-waste bags, and equipment the astronauts were done using — lies near the Lunar Module on the Moon's surface during Apollo 11.
IMAGE SCIENCE AND ANALYSIS LABORATORY, NASA-JOHNSON SPACE CENTER

SEND US YOUR QUESTIONS

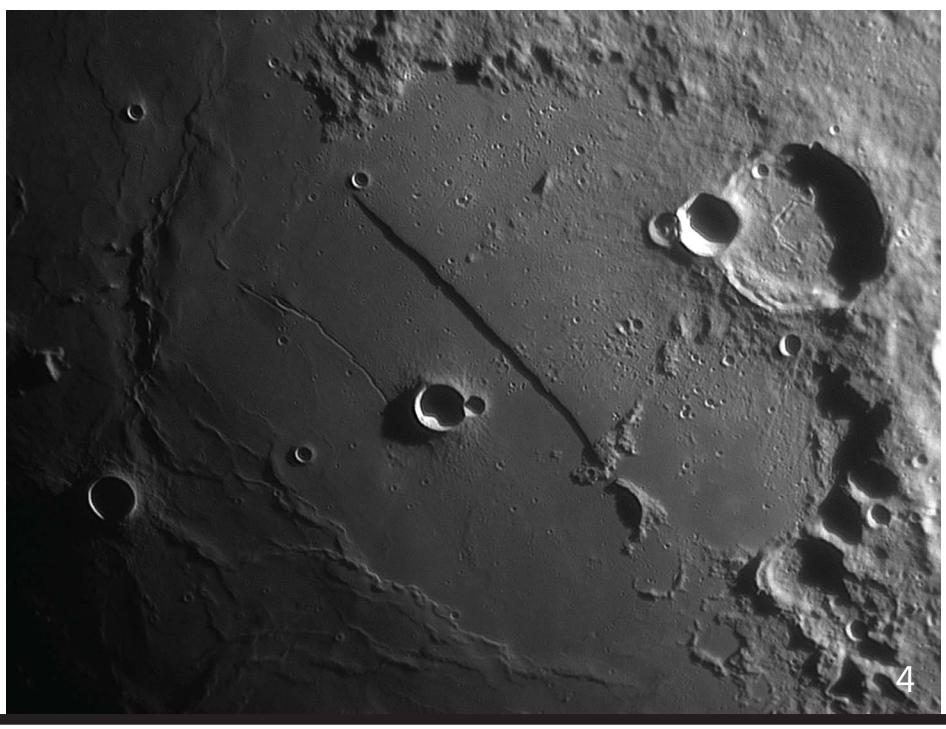
Send your astronomy questions via email to **askastro@astronomy.com**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.



1. THE FAINTER VEIL
The supernova remnant SNR G65.3+5.7 in Cygnus is comparable in size to its well-known neighbor, the Veil Nebula — but is much fainter. The object's brightest component is cataloged as Sharpless 2–91. This four-panel mosaic of the full remnant comprises 169⅓ hours of Hα/OIII/RGB data with a 2.4-inch astrograph at f/5. ***• Imran Badr***

2. A WANDERING GIRAFFE
The Giraffe Nebula (LDN 1295) is a dark nebula located in Cassiopeia (not Camelopardalis!) and is part of Beverly Lynds' *Catalogue of Dark Nebulae*. This imager captured 25 hours of RGB data with a 5-inch f/7 scope. ***• Greg Meyer***

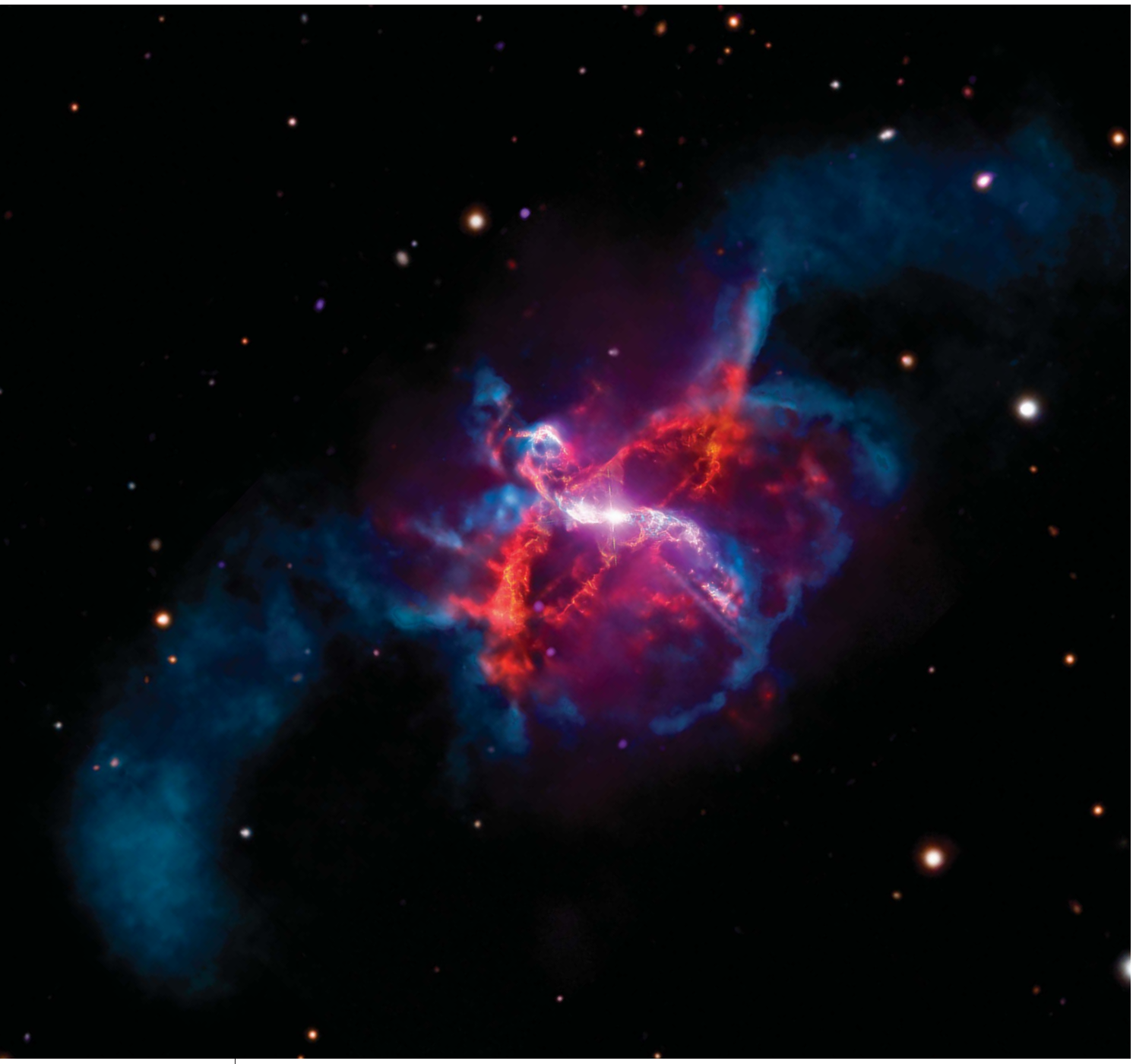
3



4

3. SPACE STATION TWINS
The International Space Station and the Chinese space station Tiangong glide across the sky above Achada do Gamo, Portugal, in this stacked image covering roughly 24 minutes on the evening of July 24, 2025. The ISS appears as the lower arc; Tiangong appeared higher in the sky just 13 minutes later. The photographer used a Sony mirrorless camera and 8mm fisheye lens at f/2.8, taking 15-second exposures at ISO 100. The foreground is a single 30-second exposure at ISO 3200. ***• José Zarcos Palma***

4. A GREAT WALL
Rupes Recta, or the Straight Wall, is a 70-mile-long (110 kilometers) lunar fault. When the Sun is low, the feature casts a shadow that makes it appear like a dramatic cliff, though in reality, its slope is gentle. ***• Jamie Cooper***



A TWISTED CLOSE RELATIONSHIP

As odd couples go, it's tough to beat the stellar pair at the heart of R Aquarii. This symbiotic binary system comprises a cool red giant and a sizzling white dwarf locked in a 44-year elliptical orbit. The enormous star pulsates in a roughly 390-day period, driving changes in temperature and brightness. It has only a tenuous grasp on its bloated outer layers, which allows the white dwarf to siphon some of this material when the two come closest. The liberated hydrogen forms an accretion disk around the white dwarf. When enough gas accumulates, it triggers an outburst that creates the surrounding nebula. At a distance of some 700 light-years, R Aqr ranks as the closest symbiotic binary to Earth. This image combines X-ray data (purple) and visible-light observations (red, orange, blue, and violet).

X-RAY: NASA/CXC/SAO; ESA/XMM-NEWTON; OPTICAL HST: NASA/ESA/STSCI; OPTICAL GROUND: DEEP SPACE REMOTE OBSERVATORIES/B. FERA AND S. MANDEL; ESO/VLT

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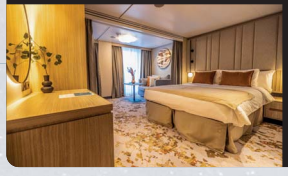

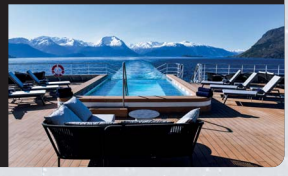

AUGUST 2026

SPANISH CASTLES

Observe the eclipse at sunset from a castle high above the pretty medieval town of Siguenza and dine in opulent surroundings. Alternatively choose the dramatic ruins of Gormaz Castle high above the plains with far reaching views towards totality.

Our various tour options take in the history of Classical Spain, the stunning scenery of the Atlantic Coast and Spain's endless Sunshine Beaches.

AUGUST 2027

NORTH AFRICA

A total solar eclipse with an extraordinary duration of over 6 minutes in Egypt will occur along the length of the North African coast. We have selected the very best locations to observe this event from, enabling you to enjoy the rich history, culture and scenery of these exotic lands.

Morocco: A diverse blend of mountains, deserts, royal cities and colourful ancient markets. Civilised and safe, it's an easy place to visit.

Tunisia: A rich Arab culture and some great antiquities and Star Wars film sets! A land where the Mediterranean Sea meets the Sahara Desert.

Siwa Oasis: Head out into the Western Deserts of Egypt and discover lush palm trees, crystal clear springs and serene salt lakes that paint a picturesque backdrop against the golden sands of the Sahara.

Luxor: The ancient capital of Egypt where history is measured in many thousands of years and there is much to see. You will certainly be sure to remember seeing a total solar eclipse from a private island in the Nile!

The Red Sea: Cooled by a gentle sea breeze, you can watch the eclipse from a high grade resort and indulge in snorkeling or diving in the remote and unspoilt colourful coral reefs.

Nile Cruise: This most famous of rivers tells its own story as you watch a panorama of history and daily life unfold along the banks, with a guiding hand from our expert guides of course!

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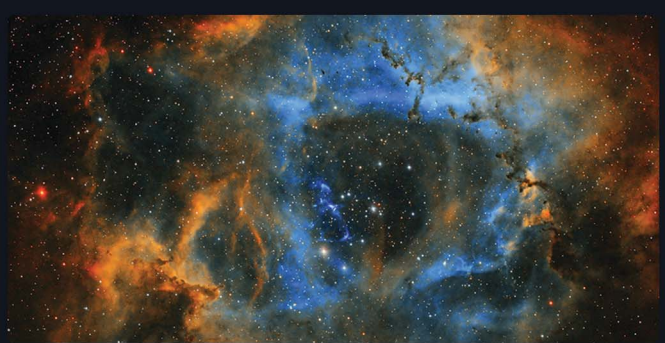
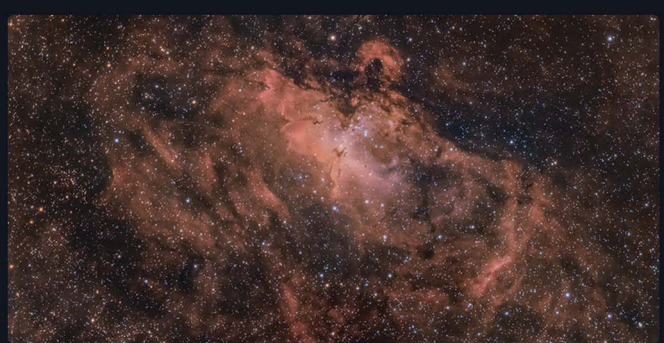


Rosette Nebula from Bortle class 8 skies (Los Angeles, CA)
Captured by Amir Cannon, Celestron Vice President of Operations
RASA 8" on Celestron CGX mount with narrowband filters and a monochrome camera



Eagle Nebula from Bortle class 9 skies (Long Beach, CA)
Captured by Chris Hendren, Celestron Technical Support Manager
RASA 8" on Celestron CGX mount with the Celestron H-alpha, H-beta, OIII Imaging Filter (#93619) and a color camera

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June 2026
An evening planet trio

June evenings offer a great chance to view three bright planets. Jupiter, Venus, and Mercury gather in the northwestern sky as darkness settles in, creating a grand sight to the naked eye and worthy targets through a telescope.

Jupiter has been wandering through Gemini the Twins since the dawn of 2026. Shining at magnitude –1.9, it easily bests the constellation's two brightest stars, Castor and Pollux. The giant planet exits Gemini and enters neighboring Cancer the Crab on June 22.

Jupiter is always an attractive telescopic sight. Although it now appears low in the sky, take a few moments to study it up close. The gas giant displays a stunning disk measuring 32" across in mid-June. Look for a pair of parallel dark belts, one on either side of a bright equatorial zone. More subtle features appear during moments of good seeing. You should also see the planet's four brightest moons, which change relative positions from night to night.

Although brilliant **Venus** begins June in Gemini, below Jupiter, it moves rapidly eastward and crosses into Cancer on the 11th and Leo on the 28th. Keep an eye out June 9, when magnitude –4.0 Venus has an attractive conjunction with Jupiter. The inner planet then lies 1.6° due north (lower right) of its larger sibling. Casual skygazers often call my planetarium at times like these wondering what they are seeing.

Follow Venus through a telescope this month and you'll see its disk grow larger while its phase wanes. On June 1, the inner planet appears 13" across and 80 percent lit; on the 30th, it spans 16" and the Sun illuminates 70 percent of its Earth-facing hemisphere.

Our third evening object appears best in mid-June. **Mercury** reaches greatest elongation on the 15th, when it lies 25° east of the Sun and stands 8° above the northwestern horizon an hour after sunset. The innermost planet shines at magnitude 0.5 from its perch to the lower left of Venus and Jupiter.

A telescope provides a nice view of Mercury. At greatest elongation, it shows an 8"-diameter disk that's 40 percent lit. Its size increases and its phase decreases as the month progresses.

Saturn rises after midnight local time all month. It begins June among the background stars of Cetus the Whale but crosses into Pisces the Fish within the next few days. The marine creatures feature no star brighter than 2nd magnitude, so the magnitude 0.8 planet stands out.

As we move further from its early 2025 ring-plane crossing, Saturn grows more spectacular when viewed through a telescope. On June 15, the planet shows a disk measuring 17" across the equator while the ring system spans 39" and tilts 9° to our line of sight. Also keep an eye out for Saturn's brightest moons. Eighth-magnitude Titan shows up in any telescope, while a 10-centimeter instrument also reveals 10th-magnitude Tethys, Dione, and Rhea.

Mars moves rapidly eastward relative to the background stars, nearly keeping pace with the Sun. That's why it rises around the same time every morning, within about 10 minutes of 4:30 A.M. local time. The Red Planet starts June in Aries the Ram and passes into Taurus the Bull on the 19th. At month's end, Mars stands within 5° of the stunning Pleiades star cluster (M45). Unfortunately, the ruddy world remains a disappointment through a telescope, showing a featureless disk just 4" across.

The Moon occults three bright objects in June. On the 17th, a thin crescent Moon passes in front of Venus for observers in northeastern South America. Two days later, Luna targets the blue-white star Regulus for those in southern Africa and much of Madagascar. Finally, on June 27 (the 28th local time), the nearly Full Moon occults the red supergiant star Antares from southeastern Australia and New Zealand.

The starry sky

Few astronomers have had a bigger impact on the science than American Henrietta Leavitt (1868–1921). More than a century ago, she discovered that Cepheid variables make superb distance indicators for stars in the Milky Way and galaxies beyond. She found a strong relationship between the period of their variation and their luminosity (or absolute magnitude).

One of my favorite Cepheids is Eta (η) Aquilae, which lies just north of the celestial equator in Aquila the Eagle. It comes into view in the east in late evening and climbs high in the north after midnight local time.

For a more southerly Cepheid, look no further than Norma the Square. This constellation contains two fine open star clusters: NGC 6067 and, 4° to the south-southeast, NGC 6087. The latter is also the 89th entry in the Caldwell catalog, a compendium of deep-sky objects the English astronomer Sir Patrick Moore complied.

Caldwell 89 shines at magnitude 5.4 and, while it shows up to the naked eye from a dark site, it's a splendid sight through binoculars or a small telescope. It contains a bright Cepheid variable, S Normae, that varies between magnitudes 6.1 and 6.8 over a period of 9.75 days. It's easy to identify because it's the brightest star in the cluster. Observe it for a week or two to see if you can detect its change in brightness.

S Nor shines brightly enough that astronomers once thought it might be a foreground object. But researchers confirmed that it belongs to the cluster in 1955.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. June 1
8 P.M. June 15
7 P.M. June 30

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

JUNE 2026

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon is at apogee (406,366 kilometers from Earth), 4h33m UT

3 Asteroid Juno is stationary, 19h UT

4 Jupiter passes 6° south of Pollux, 11h UT

8 Last Quarter Moon occurs at 10h01m UT

Venus passes 5° south of Pollux, 16h UT

9 Venus passes 1.6° north of Jupiter, 12h UT

The Moon passes 4° north of Neptune, 19h UT

10 The Moon passes 6° north of Saturn, 12h UT

12 The Moon passes 6° north of Mars, 21h UT

13 The Moon passes 5° north of Uranus, 19h UT

14 The Moon is at perigee (357,197 kilometers from Earth), 23h20m UT

15 New Moon occurs at 2h54m UT

Mercury is at greatest eastern elongation (25°), 20h UT

16 The Moon passes 3° north of Mercury, 20h UT

17 The Moon passes 3° north of Jupiter, 7h UT

The Moon passes 0.3° north of Venus, 20h UT

19 The Moon passes 0.3° south of Regulus, 15h UT

21 Winter solstice occurs at 8h25m UT

First Quarter Moon occurs at 21h55m UT

23 Mercury passes 7° south of Pollux, 19h UT

27 The Moon passes 0.4° south of Antares, 15h UT

28 The Moon is at apogee (406,265 kilometers from Earth), 7h11m UT

29 Mercury is stationary, 2h UT

Full Moon occurs at 23h57m UT

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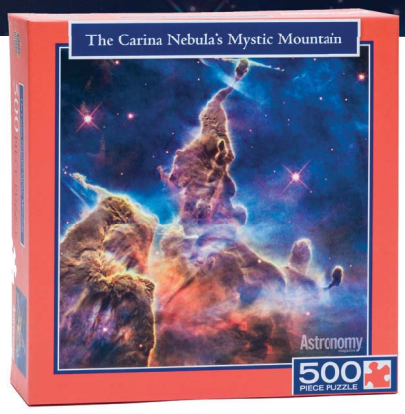

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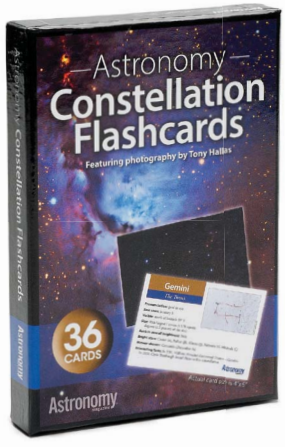

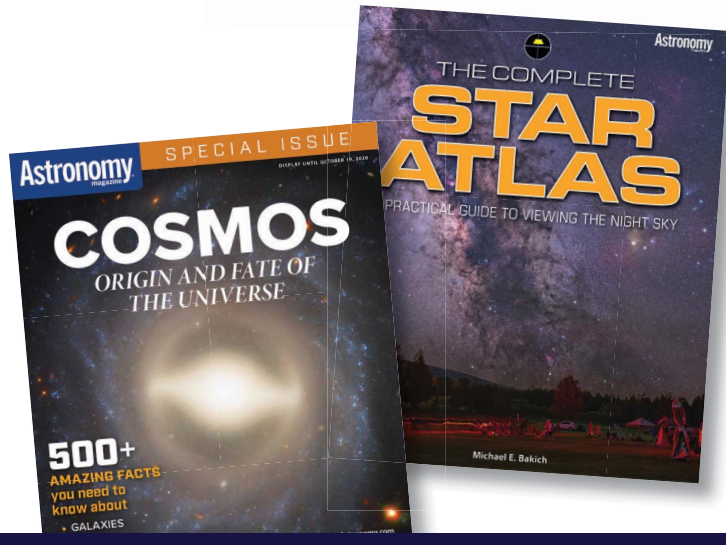

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